

STRP Report 15

Design and Implementation of Transit Priority at Signalized Intersections:

A Primer for Transit Managers and a
Review of North American Experience

a project managed by
un projet dirigé par



Canadian Urban Transit Association
Association canadienne du transport urbain

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Review of North American Experience**

Prepared by:

Paradigm Transportation Solutions Ltd.

November 2000

CUTA Mission Statement

CUTA is the association of providers of urban transit services, suppliers and related organizations in Canada. Its mission is to promote the role of urban transit in enhancing mobility, and to support its members in the fulfilment of their mandate.

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Abstract The efficiency of bus transit operations in urban areas is directly affected by traffic congestion and delay at signalized intersections. In addition, reduced speeds and variability of schedule adherence reduces the attractiveness of the service for transit customers. Priority for transit buses at signalized intersections is one strategy to alleviate the negative impacts of congestion and delay. However, there has not been extensive experience in North America with transit priority at signalized intersections. This report was prepared to assist transit managers and other professionals plan, design and implement transit priority measures successfully. The report first provides a Primer for Transit Managers that includes an overview of transit priority concepts, followed by a primer on pertinent traffic engineering considerations. Using a comprehensive literature review as a basis, the Overview of Transit Priority addresses: bus lanes, queue bypass lanes, bus priority access to freeways, traffic signal priority, operational priority, regulatory transit priority measures, and comprehensive transit priority plans. The Primer on Traffic Engineering Considerations includes: traffic safety, traffic flow characteristics, traffic signal timing, traffic control equipment, and transit signal priority The report then presents a number of case studies of transit signal priority including: Toronto, Ottawa, Suburban Chicago, Bremerton (Kitsap Transit), WA and Tacoma (Pierce Transit), WA. The case studies illustrate different approaches. The report finally provides a number of conclusions drawn from the case studies, as well as planning and implementation guidelines for transit signal priority. All five case studies report improved operations for buses and no significant traffic problems as a result of transit priority. Traffic signal priority is a measure that can improve transit services and efficiency. However, it is also noted that clear policy direction from elected bodies and a close working relationship between transit and traffic staff are important elements of successful projects.		
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1.0 INTRODUCTION

The quality of life and the economic health of Canadian urban areas is directly dependant on an efficient, effective and sustainable transportation system. However, in the larger urban centres across the country, transportation systems have become increasingly congested and are having a variety of undesirable impacts on the environment. The need for change is generally recognized but the required changes are not clear and the apparent costs of many proposed changes are not affordable for the agencies involved.

Convenient and affordable public transit service is recognized as an important component of an effective transportation system. For transit systems to continue to be effective, new and improved methods of delivering services must be developed. It will be essential, however, for these methods to be affordable for the communities involved. Transit priority is one approach that offers the potential for improved service at a reasonable cost. This report has been prepared as a resource document for public transit managers to develop methods of delivering better services through transit priority applications.

1.1 Study Purpose

The operation of transit in urban areas is significantly affected by general traffic congestion. This is particularly the case with bus transit services, which generally operate on public streets in mixed traffic conditions. Traffic congestion impacts bus services in two important ways. As congestion increases, the average operating speed of buses is reduced and a greater number of buses is required to provide the same frequency of service. This in turn increases ongoing operating costs of the system and requires additional funding or service reductions in other areas. Secondly, as the speed and reliability of bus operations is reduced by congestion, the attractiveness of the service to customers is reduced and ridership can be expected to decline. Again, this has the downward spiral affect of requiring increased funding to maintain attractive service levels or services must be reduced to offset the loss in passenger revenue.

In response to the problem of traffic congestion, many cities have developed operational measures to provide buses with priority over mixed traffic to maintain and improve bus operations. Particularly in European cities, there are many examples of transit priority being used as part of an overall strategy to respond to urban travel needs in a manner that supports the broader urban goals of high quality of life, environmental sustainability and economic prosperity. In North America, there has not been the same level of experience with bus transit priority. The Canadian Urban Transit Association (CUTA) identified the issue of **transit priority** as one of the strategic issues facing the transit industry, requiring exploration through CUTA's Strategic Transit Research Program (STRP). An initial study "STRP Report 9-1 Transit Priority Traffic Control Systems: European Experience" was published in 1994. This report documented in-depth case study experience in five European cities; namely, London, Stuttgart, Zurich, Nancy and Angouleme.

At the time of the initial study, there was little focus on transit priority in North America. However, the situation has changed substantially since then. In December 1999, CUTA conducted a survey of all transit systems in North America with over 100 buses. The results of the survey are summarized in Appendix B. Eighty six transit systems responded (74.8 % response rate). The survey results show the growing interest in this issue. Thirty six percent of the respondents indicated that some traffic intersections in their area have already been equipped with transit signal priority and 44.2% of respondents have transit signal priority projects underway. All told, 69.8% of transit systems with over 100 buses have implemented or plan to implement within the next 5 years, transit signal priority. This clearly underscores the interest in this technology.

The current study, prepared by Paradigm Transportation Solutions Limited, explores current North American experience and issues related to transit priority, in order to assist transit managers and traffic engineers in developing approaches to improving bus operations in Canadian urban areas through the use of transit priority measures. The stated goal of the project was as follows:

To explore experience with transit priority systems and measures at signalized intersections in North American cities in order to identify the specific operating strategies being used and key design and implementation issues, and to develop for transit managers a primer document that outlines key basic traffic engineering concepts, traffic operating strategies, potential technological and communication options, and key issues.

1.2 Scope of the Study

This project has been carried out in three main steps. The first step was an extensive review of available literature on transit priority, particularly on North American applications. A summary overview of the material is provided as Appendix A to this report. To further support the research effort, CUTA conducted a survey of transit priority systems across North America. A summary of the survey results is provided in Appendix B of this report.

Based on the literature review, an overview of transit priority measures was prepared as provided in Chapter 2.0 of the report. Also, to assist transit staff in developing a broader perspective of transit priority, a general overview of traffic engineering considerations was developed and is provided in Chapter 3.0 of the report. This overview is very general and is intended to help transit managers better understand some of the traffic engineering challenges that must be addressed in a successful transit priority project.

The literature review, together with the CUTA survey helped to identify possible case studies for this project. A number of cities were initially identified and contacted. From this group of cities, five were selected as case studies. The main factors used in making this selection were as follows:

- Case studies were selected that provided experience with a variety of methods and different city characteristics.
- To support the investigation of case studies, those projects that had good documentation were preferred.
- Case studies were selected that represented more recent experience.

- ◄ Cities that appeared to be active in developing transit priority, based on the CUTA survey, were preferred.

Based on this review, the cities selected were Toronto, Ottawa, Suburban Chicago (Cermak Rd), Bremerton in Kitsap County, WA, Tacoma in Pierce County, WA. Contacts were made with both transit and traffic officials in each of these communities by telephone and e-mail. The officials were all extremely helpful in providing information and reviewing the draft descriptions of the case study documentation. The names of the main contacts are listed in the case study sections of the report. Chapters 4.0 through 8.0 provide a description of the case studies.

The final step in the study was the preparation of study conclusions and suggested guidelines for transit managers, based on the research carried out. The conclusions are outlined in Chapter 9.0 of the report and suggested guidelines for transit priority projects are discussed in Chapter 10.0.

2.0 OVERVIEW OF TRANSIT PRIORITY

Priority measures for public transit vehicles have been used for a number of decades in Europe, North America and other parts of the world. In this report, the primary area of interest is priority for buses in urban traffic situations. A wide variety of measures have been developed and demonstrated in many different cities for bus priority in urban traffic. These techniques tend to be innovative in nature and, as experience has been gained with transit priority measures, other new forms of transit priority have evolved. The purpose of this section of the report is to provide an overview of measures that have been developed to date and shown to be feasible in operation. Since transit priority measures have tended to be innovative in their development, the list of possible measures is certainly not complete. However, it does provide an outline of some transit priority methods for consideration.

2.1 Bus Lanes

Bus lanes are a common transit priority measure and have been used in many different cities. In general, bus lanes are roadway lanes designated specifically for bus use although there are cases where these designated lanes can also be used by high occupancy vehicles (HOV), bicycles or by emergency vehicles such as police, ambulance and fire. Bus lanes may be created by designating an existing travel lane for this use or by adding a new lane to the roadway as a bus lane. Some of the common types of bus lanes are discussed below.

2.1.1 With-Flow Bus Lanes

With-flow bus lanes can be described as lanes designated for bus-only use that operate in the same direction as the adjacent traffic lanes. Typically, these would be curb lanes but this is not always the case. Curb lanes facilitate passenger stops at curbside. However, other lanes could be used either for express bus services or bus services with passenger stops at non-curb locations (e.g., protected islands). With-flow bus lanes are usually designated by pavement markings and overhead signing to notify general traffic of the restricted uses. In some instances the bus lanes may be physically separated from the general traffic lanes by curbs or other separation devices. An example illustration of a with-flow bus lane is shown in Figure 2.1 below.

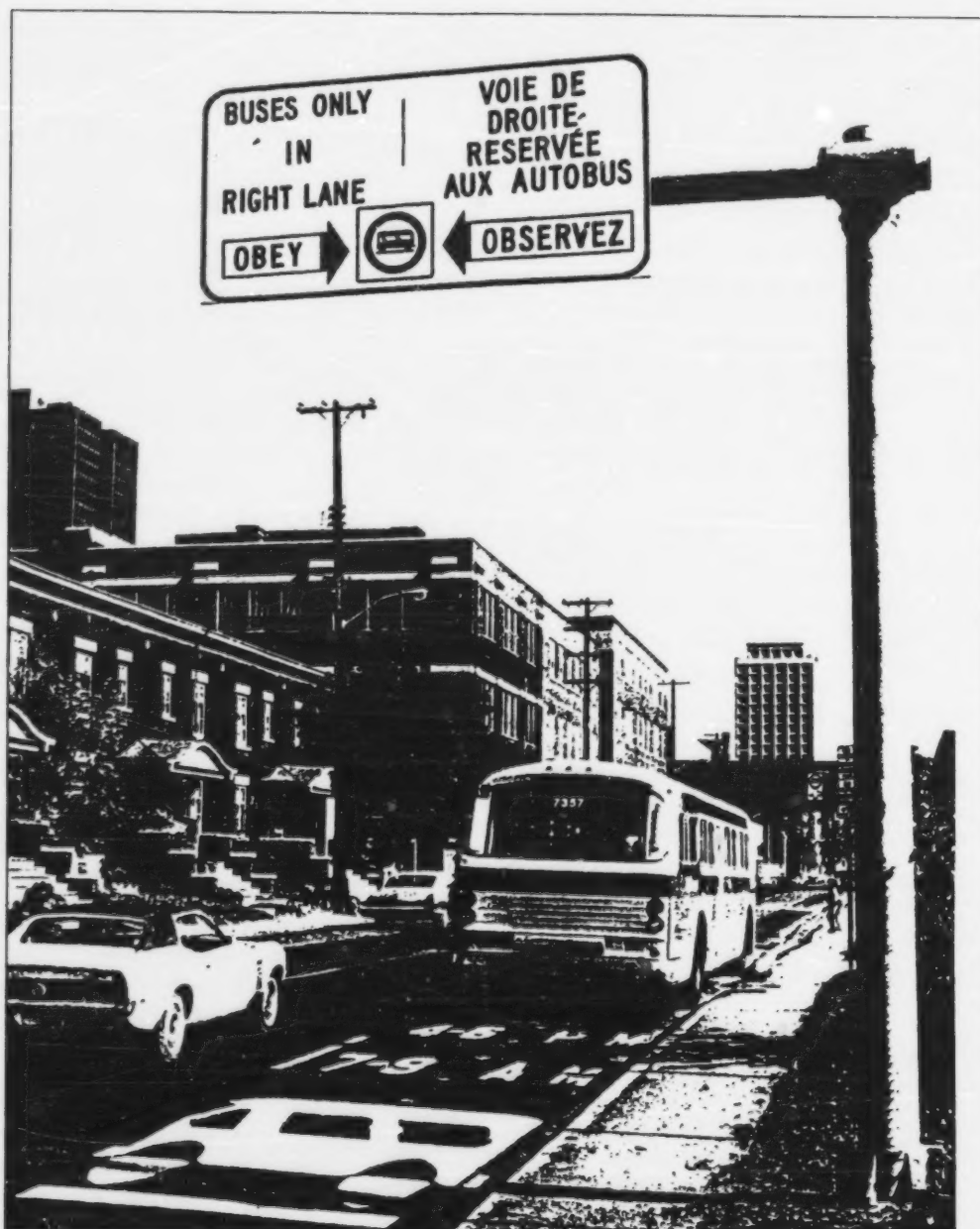


FIGURE 2.1: ILLUSTRATION OF WITH-FLOW BUS LANE (REF. 1)

With-flow bus lanes are typically used where general traffic is heavy and creates excess delay for bus operations and where there is a higher volume of buses that can take advantage of the lanes. This often occurs in the more central areas of a city on busy routes crossing geographic barriers such as rivers or railway lines. Warrants are sometimes suggested for determination of where with-flow bus lanes would be feasible. Typically, these warrants consider bus-lane feasibility on the basis of the volume of buses that would use the lane.

Warrants are often based on empirical judgment, the overall impact on person delay through the corridor or some other criteria. In any event, warrants often over-simplify the variety of issues involved and should only be used with caution.

Some of the specific advantages of with-flow bus lanes, in addition to general transit priority benefits, include:

- With-flow lanes generally involve less change than other configurations, which means that they can be applied during certain time periods (e.g., peak periods), they can be maintained with normal maintenance operations and there is less physical change required for implementation.
- There is less disruption of normal traffic patterns.
- They can usually be readily utilized for other uses, such as emergency vehicles, if needed.
- The priority advantage being given to buses is apparent to adjacent motorists and may provide some incentive for change in modal choice behavior.

There are also some disadvantages to with-flow bus lanes as follows:

- At right turn locations it may be necessary to allow vehicles to use the lane for a specified distance (the most common approach) or to require right turns from the second lane. This creates some safety concerns and reduces the operational efficiency of the bus lane.
- Where local curbside bus stops are present for some buses only, the effectiveness of the bus lane can be reduced by these buses blocking through buses.
- With curb lanes adjacent to general traffic lanes, enforcement is necessary to ensure the bus lane is not abused by general traffic.
- A curbside bus lane generally eliminates the possibility of on-street parking.
- On streets with a higher number of driveways, the traffic entering and exiting at these points causes greater flow disruptions and increased risk of accidents.
- For with-flow bus lanes in other than curbside lanes (e.g., median bus lanes), passenger access requires street crossings and additional width for a passenger refuge island.
- In a congested corridor, elimination of a general traffic lane may create vehicular congestion that is a greater disbenefit than the improved bus operations.

There are a variety of other factors to be considered as well. If a with-flow bus lane in a congested corridor has a reasonable volume of buses using the lane, then the general public will better appreciate the restriction on general use of the lane and enforcement may be less of a problem.

There are various ways of designing the operation of the bus lane at signalized intersections. Where right turns are required for general traffic, there is usually a designated area where general traffic can utilize the bus lane for turning purposes. The bus lane may be designed to allow buses to have first priority in passing through the intersection or, in some cases the bus lane may be ended before the intersection to provide greater vehicular capacity through the intersection. Obviously these different techniques have to be assessed in light of specific local circumstances.

In the layout of a with-flow bus lane project, the beginning and the end of the bus lane require special attention. At the beginning of the lane, it is desirable to start in a location that does not create an unnecessary bottleneck. At the end of the lane, it is important to enable buses to make a smooth transition back into regular traffic.

There are many examples of bus lanes in Canada, USA and other countries. In some of these cases, bus volumes in excess of 150 buses per hour have been accommodated. Also, in some cases reductions in bus travel time of over 20% have been reported (1) (*Numbers in brackets refer to references at the end of the text.*)

2.1.2 Contra-Flow Bus Lanes

Contra-flow bus lanes are bus lanes traveling in the opposite direction to the general traffic flow. This form of bus lane is not used as commonly as with-flow lanes but it does offer some different features. A typical example of a contra-flow lane would be a bus lane traveling in the opposite direction as general traffic flow on a one-way street, keeping to the right (in Canada). Another application could occur on a divided street where buses travel in the lane adjacent to the median but opposing the general traffic direction. This enables the buses to use the median as a passenger stop area. Contra-flow lanes on one-way streets can be thought of as a form of two-way street with only buses traveling in one direction. An illustration of a contra-flow bus lane is provided in Figure 2.2 below.

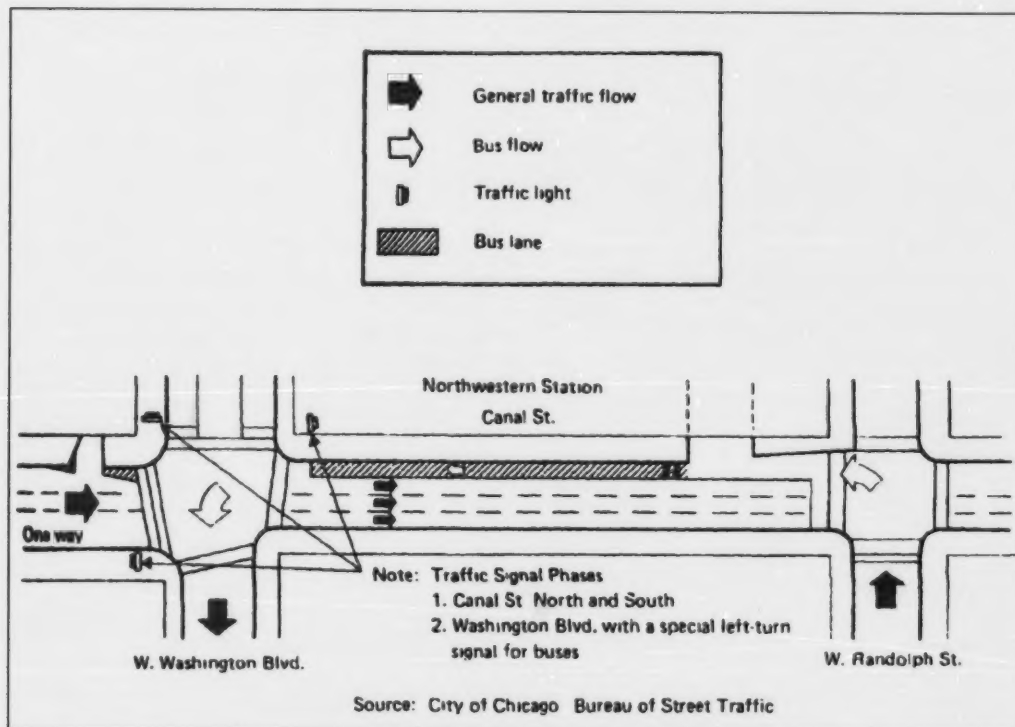


FIGURE 2.2: ILLUSTRATION OF CONTRA-FLOW BUS LANE (REF. 1)

Contra-flow bus lanes offer some advantages as compared to with-flow bus lanes. A few key advantages are as follows:

- * The problem of enforcement is not as significant with contra-flow lanes because it is more difficult for general traffic to get into and out of the bus lane. The opposing nature of the traffic tends to make contra-flow lanes self-enforcing. It is not as simple as a lane change while traveling in the same direction as the bus lane.
- * Contra-flow lanes can provide the capability of providing two-way transit service along a one-way street. This could be a significant service consideration if the alternate route was some distance away.
- * The operational conflicts at right-turn locations are reduced as compared to with-flow bus lanes. Contra-flow lanes on an otherwise one-way street effectively create a situation where traffic is controlled as if it were a two-way street (but with only buses in one direction). In some situations this may improve bus travel times as compared to a with-flow bus lane.

There are also a few challenges with contra-flow lanes that should be noted:

- * Where contra-flow lanes are introduced on streets that previously had one-way traffic for a lengthy period of time, the safety of pedestrians and driveway traffic is a significant concern. Pedestrians and drivers tend to look in the direction that general traffic is coming from and forget to look for buses coming from the opposite direction.
- * On crowded downtown streets, contra-flow lanes are more difficult for buses to turn into from a side street due to oncoming traffic in the adjacent lane and tendency for downtown street corners to have fairly short turning radii (i.e., sharper corners). This is often compounded by the fact that on one-way streets, the street corners often have shorter turning radii to facilitate pedestrian crossings.
- * At the end of a contra-flow lane, it is necessary to make provisions to prevent oncoming traffic from entering the bus lane. This can be accomplished in different ways but usually some channelization with curbs is required to ensure traffic safety. This situation, together with the previous point, usually requires more geometric changes to install contra-flow lanes with a resultant higher cost.
- * At signalized intersections, the implementation of contra-flow lanes means that a form of two-way traffic control is required. This again creates an additional cost for traffic control equipment and it also reduces many of the traffic operational advantages of one-way streets.

A significant consideration with contra-flow lanes is the provision of bus stops. If stops are required for local passenger service, the stopped buses will usually require following buses to stop. If a mix of local and express buses is using the contra-flow lane, further consideration of bus stop arrangements is advisable.

The lane width for a contra-flow lane should be at least 4.0 metres, recognizing normal bus sizes. It may be advisable to provide additional width for greater separation from opposing traffic and to facilitate buses turning into the lane at turning locations. A variety of techniques may be used to separate the contra-flow lane from opposing traffic lanes, such as painted lines, raised curbing, overhead lane control signs or a combination of these. Signing is important, not only for safe operation of buses and vehicular traffic but also for pedestrians, to make them aware of the contra-flow lane. In some instances (1), barriers have been installed along the front of the sidewalks to improve pedestrian safety. Generally a contra-flow lane consists of a single lane that is effectively blocked by stopped vehicles in the lane. Whether these vehicles are local buses or other types of vehicles such as delivery

vehicles that have been permitted in the lane, it may be advantageous to provide extra widening at specific locations. This could be in the form of a bus bay or just a section of a widened lane.

In summary, contra-flow bus lanes offer advantages in some situations, as compared to with-flow bus lanes. They are likely to involve additional cost due to requirements at the ends of the lanes and they may present some safety risks following implementation. However, enforcement is usually easier and operational effectiveness may be improved as compared to a with-flow lane.

2.1.3 Freeway Bus Lanes

Freeway bus lanes are described here as a special case of bus lanes. The use of bus lanes on freeways has been particularly popular in the USA but there are also examples in Canada and elsewhere. There are a wide variety of freeway bus lanes applications. With-flow lanes on freeways have been used, both as shoulder lanes and median lanes. Contra-flow lanes have been used in a number of cities, usually with the contra-flow lane on the off-peak side of the freeway. There are also examples of centre median busways built into the freeway corridor. In almost all cases the bus lanes have been implemented on relatively congested urban freeways focused on the city centre. The bus lanes provide a form of high capacity and high-speed transit service that may provide capacities approaching the capacity of rail transit systems. In the USA, freeway bus lanes are often used by high occupancy vehicles (HOV), as well as buses, to provide the highest possible person-carrying capacity. In many of these cases the lane is primarily an HOV lane and may not provide any significant transit benefits. Bus lanes on freeways are well suited to express bus operation over longer distances.

Some of the advantages of freeway bus lanes are as follows:

- Freeway bus lanes are a very cost-effective form of "mass transit" which may be implemented at a lower capital cost than other options.
- Freeway bus lanes can provide a high level of transit capacity and greatly reduced travel times as compared to conventional bus service in mixed traffic.
- Freeway bus lanes may also offer the option of including HOV lanes to further improve overall corridor capacity.

Some of the challenges related to freeway bus lanes are as follows:

- Utilizing an existing lane from a crowded freeway corridor requires a reasonable volume of buses and other lanes users such as HOV to maintain public support. Experience in the USA has indicated the public is more likely support this kind of project if it is seen to be well used.
- Adding lanes to a crowded freeway corridor is usually costly due to the civil and structural work involved. However, these costs are likely substantially less than developing a new rapid transit corridor in most cases.
- Freeway bus lanes are only effective for express bus operations.

As noted earlier there are a wide variety of applications of this form of priority and usually the projects involve more significant capital expenditures. Also, they tend to be more applicable to larger urban areas with higher bus volumes. However, the range of possible

applications also provides some opportunity for innovation. An example configuration of a contra-flow freeway bus lane using the off-peak side of the freeway is provided in Figure 2.3 below. This same concept could be applied to a major arterial roadway with a heavy peak orientation of traffic volumes.

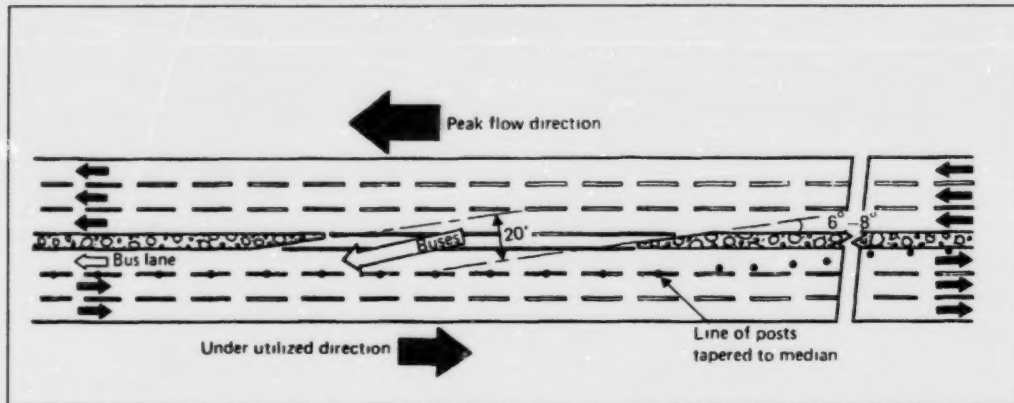


FIGURE 2.3: CONTRA-FLOW FREEWAY BUS LANE (REF. 1)

2.2 Queue Bypass Lanes

Queue bypass lanes or queue jump lanes are a special adaption of the bus lane concept, which utilize a bus lane and other traffic control measures to enable buses to travel through congested areas with reduced delay. This form of transit priority often involves considerable innovation to find methods of enabling buses to avoid the congestion that is normally encountered at a heavily congested area. The concept is best illustrated by describing a few examples.

Figure 2.4 shows a very typical queue bypass lane. In this example there are three lanes approaching an intersection, consisting of a curbside bus lane and two mixed traffic lanes. By providing a special bus only advance signal phase, buses waiting in the bus lane are allowed to advance ahead of the mixed traffic waiting at the signal.

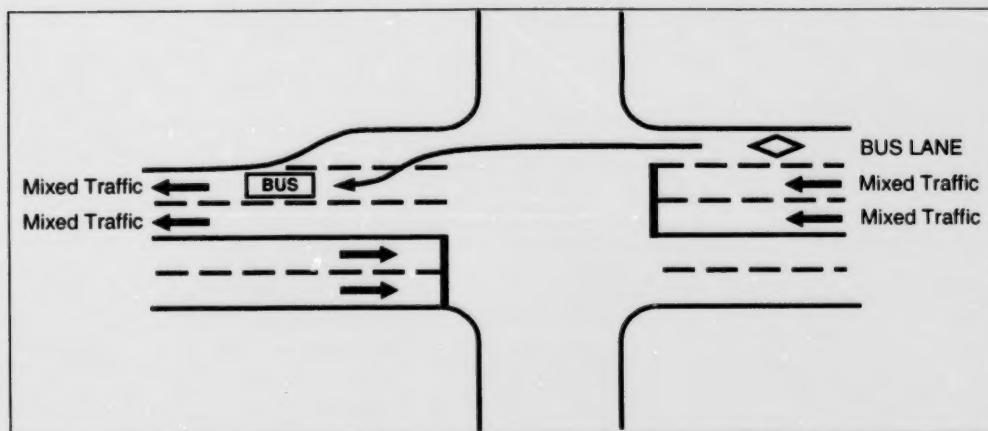


FIGURE 2.4: TYPICAL QUEUE BYPASS LANE

Another variation of a queue bypass lane is illustrated in Figure 2.5. In this instance, a right turn channelization island is modified to provide a short bus-only lane, enabling buses to travel straight through the intersection. This case might be effective if the through movement was heavily congested and the right turn movement was very light, allowing the bus to advance to the front of the mixed traffic queue. The configuration would be most effective for bus operations if a special bus only advance signal phase is provided at the intersection.

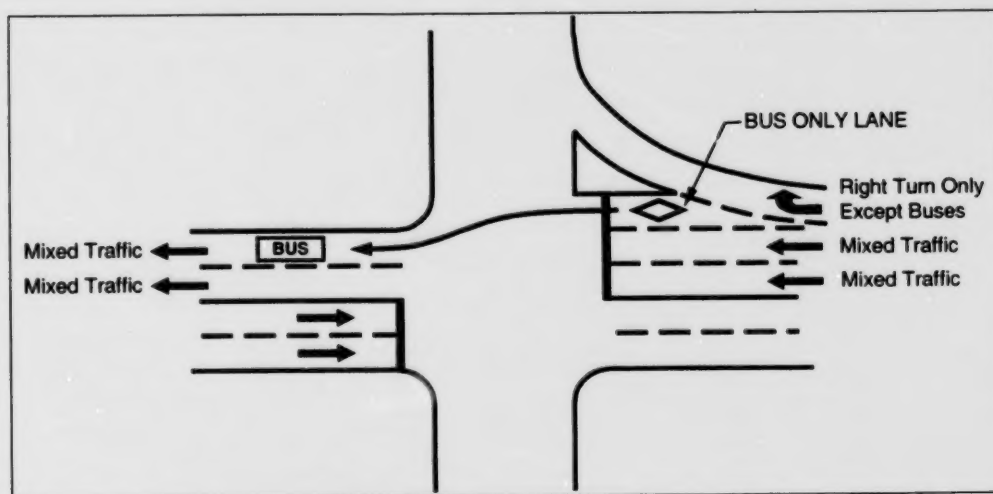


FIGURE 2.5: EXTENDED RIGHT TURN LANE FOR BUSES

A different form of queue bypass measure is illustrated in Figure 2.6. In this case from Ottawa, the queue bypass is provided by having the intersection stop bar advanced or setback a distance from the intersection, rather than relying on a separate bus lane. By designating the curb lane as "Right Turns Only - Except Buses", buses are able to travel past

the stop bar and change lanes into the through lanes. When the signal provides the through green phase, the buses are at the front of the queue and are able to advance through the intersection ahead of the mixed traffic. This form of priority is one that will require some enforcement and will be more readily accepted by the public if it is seen to be well used.

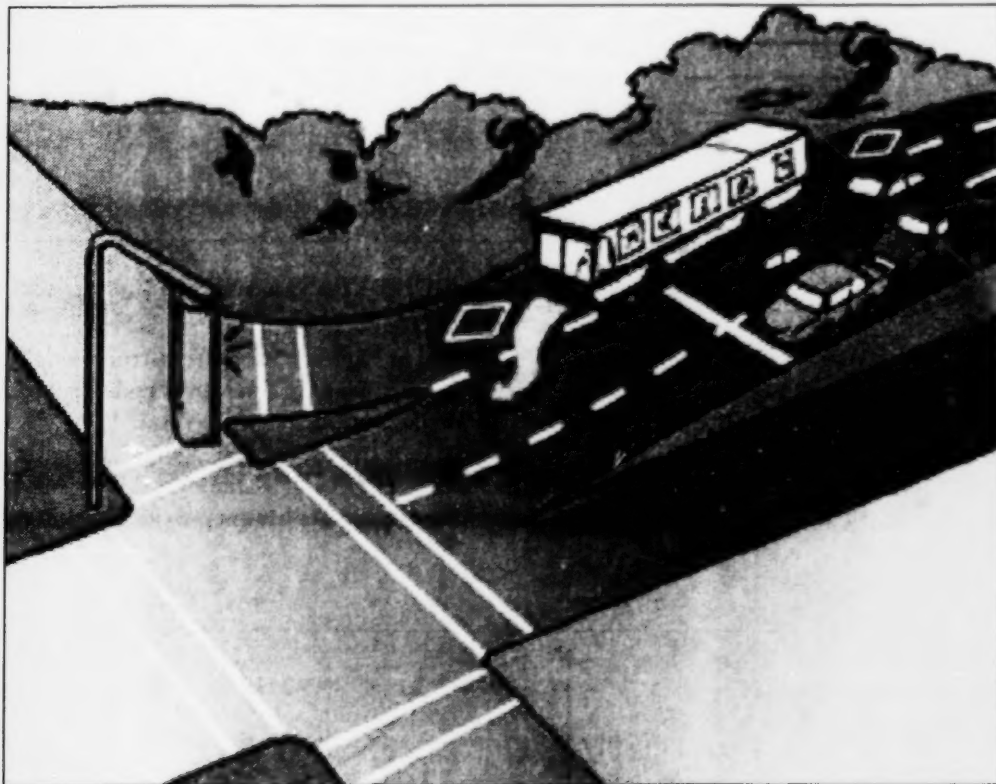


FIGURE 2.6: ADVANCED STOP BAR FOR MIXED TRAFFIC

Another form of queue bypass arrangement at T intersections is shown in Figure 2.7. In this case, a special left turn lane is added for buses only. The buses are able to reach this lane by traveling in the right lane, past queued vehicles waiting to turn left. From the bus only lane, buses are able to make a left turn into the second lane on the next left turn phase. This does not require a special signal phase but could be improved by that feature. Another variation on this particular example would be to designate the right turn approach lane as "Right Turns Only – Except Buses". If there were not enough space available for the extra bus only left turn lane, the variation would still give buses an opportunity to bypass a queue in the left turning lane.

The foregoing is intended to illustrate the range of queue bypass transit priority measures. There are many others that may be better suited in specific situations. The primary advantage of queue bypass lanes for buses is that the measure, by definition, tends to focus on critical

areas where buses are encountering excess delays and schedule problems. By developing custom measures to respond to the specific problem situation, hopefully the best results are achieved for the investment. In developing queue bypass bus priority options, it should be recognized that considerable traffic engineering effort might be required to find an appropriate solution. This will usually involve collection of reliable traffic counts and other data, analysis of a variety of alternatives including possible geometric changes and the careful evaluation of these options. The experience of a number of transit agencies (2,3) with queue bypass bus priority measures would indicate that the effort and investment is warranted.

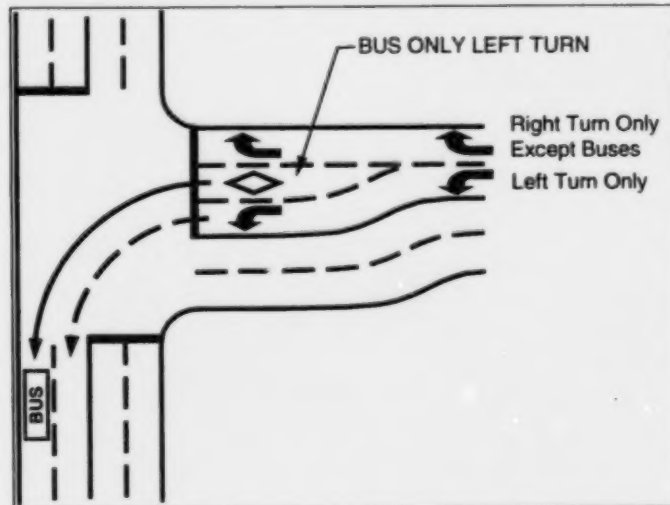


FIGURE 2.7: SPECIAL TURN PROVISION FOR BUSES AT T INTERSECTIONS

2.3 Bus Priority Access to Freeways

A transit priority measure that has been found to be effective, particularly in the United States, is the provision of priority for buses accessing an urban freeway. This is an option in cases where the situation is not suited to providing full bus lanes along the freeway but the freeway facility can still be effectively utilized for transit operations. Some of the potential options for providing bus priority access to freeways are discussed below.

- The provision of a bus only ramp to a freeway may be effective in specific circumstances. For example in a congested downtown area, the mixed traffic access to a freeway will likely be heavily congested in PM peak hours. The provision of a separate ramp at a different location may enable bus traffic to reach the freeway much more quickly by not having to travel on the congested routes leading to the access ramp and the ramp itself. This kind of measure however, is likely to involve some significant civil works and require capital expenditures. Depending on the situation, a project of this type could also be combined with an HOV facility to increase the benefits realized.

- Provision of priority at a freeway ramp under a ramp metering operation can be an effective way to provide easy access to a freeway facility. In many cities ramp metering strategies are used to keep the mainline sections of the freeway operating at desired levels of service. In these cases, the congestion is usually contained at the access ramps and the routes leading to these ramps. A bus only bypass can be an effective way to enable buses to avoid much of this congestion. An example of a bus priority access at a metered freeway ramp is shown in Figure 2.8 below.
- Provision of priority at tollgates is another variation on this particular strategy. While toll facilities are not widely used in Canada, the growing congestion in larger urban areas is likely to lead to road tolls becoming more common. Toll collection points may become areas of significant congestion. If buses are using the facility, these are obvious points to investigate a form of bus priority access.
- Ramp connections for bus route transfer connections is an effective method of combining limited stop express operations along a freeway with the need to provide passenger connections to bus routes on cross streets. Figure 2.9 illustrates an arrangement used by OC Transpo in Ottawa, Ontario to facilitate these connections and provide priority for the buses on the ramp connections to the cross street to minimize the delay involved. This arrangement can work well in combination with bus lanes on the freeway to provide efficient operations and meet passenger service needs.

Bus priority access to freeways is an option that should be given consideration where a congested central area is served by a freeway corridor. Freeway facilities offer various opportunities to transit systems to provide a higher speed and capacity service that also may achieve a much better utilization of an existing freeway facility.

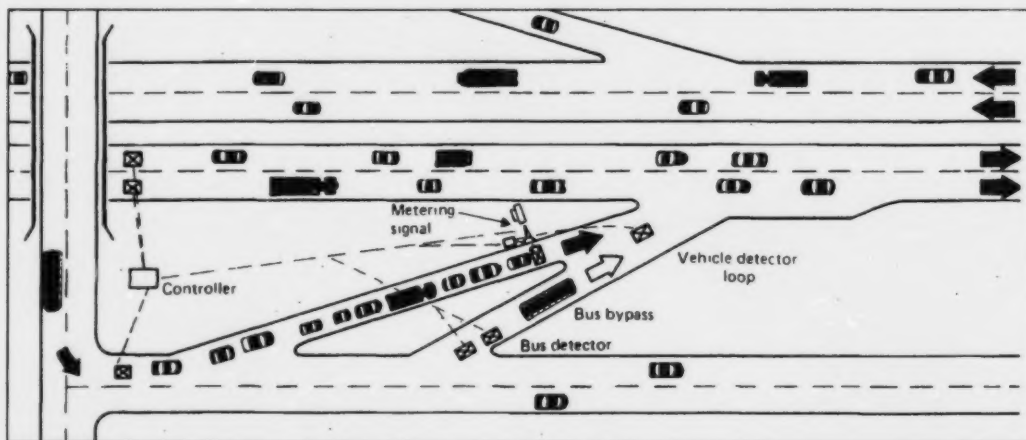


FIGURE 2.8: BUS PRIORITY ACCESS TO FREEWAY (REF. 1)

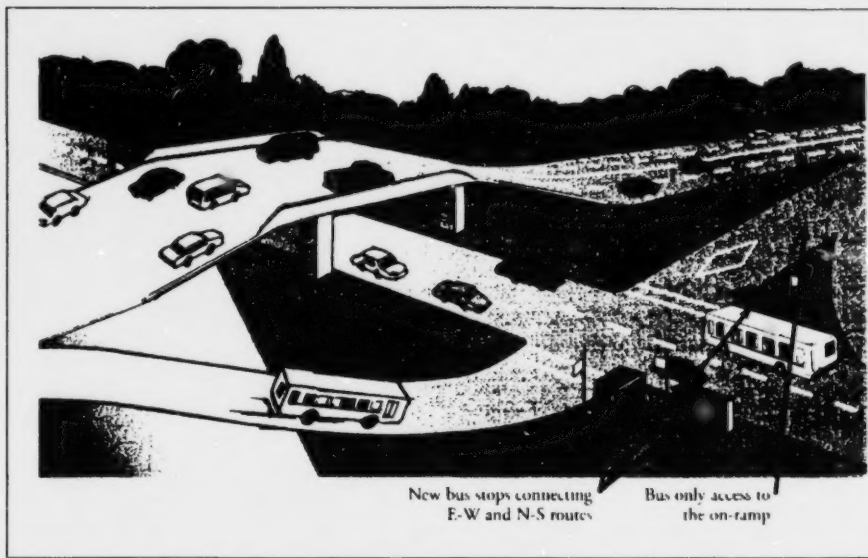


FIGURE 2.9: BUS PRIORITY RAMP CONNECTIONS

2.4 Traffic Signal Priority

Traffic signal priority for buses has been used for a number of decades in Europe, as documented in CUTA's previous study (3), but it is a newer concept in North America. In urban areas, the efficiency of bus operations is significantly affected by the delay at signalized intersections. The provision of transit priority at traffic signals can reduce this delay significantly and provide a number of benefits to the public transit services, as follows:

- Reduced bus travel time on high frequency routes can enable the same frequency and capacity to be provided with fewer vehicles, resulting in savings in operating costs.
- Priority at traffic signals can reduce the variability of bus travel time and improve schedule adherence, making the bus operators task of keeping to schedule easier.
- The reduced travel time and improved schedule adherence provide an improved service to transit passengers and potentially lead to increased ridership.

While there are a wide variety of traffic signal priority measures for buses, they can be generally described as passive priority methods and active priority methods. A general description of some of these measures is provided below and some actual case study examples are discussed in Chapters 4.0 to 8.0 of this report.

2.4.1 Passive Traffic Signal Priority

Passive traffic signal priority measures can be described as measures that are not capable of detecting and responding to buses on a real-time basis. In these cases, measures are implemented through the traffic signal control system that have been designed to provide

priority to bus operations. Some examples of passive traffic signal priority measures are as follows:

- Splitting of the normal cycle phase can be used to reduce delay to buses using a particular phase. This would be utilized in cases with an intersection with three or more phases in the normal signal cycle. During the cycle, the phase serving the bus movements can be repeated to reduce bus waiting delay for the normal single phase.
- Special signal phases for buses have been used in situations where there is normally a heavy volume of buses. Recently, the Ontario traffic legislation has been amended to provide a special transit signal display that consists of a vertical white bar (sometimes referred to as "cigar signal") on a black background. Similar signal displays are commonly used in Europe and have been developed for transit vehicles in other Canadian jurisdictions. These signal displays may be used in the normal signal cycle to provide selective control of transit vehicle operations. A common application would be as a special advance phase for buses in conjunction with queue bypass bus lanes, as discussed previously.
- The normal traffic signal cycle time is adjusted to better accommodate buses. One example of this is the use of shorter cycle times to reduce delay where a significant number of buses are using one particular intersection approach, such as the entrance from an off-street terminal to an arterial roadway. Normally, longer cycle lengths increase the capacity of a signalized intersection but also increase the amount of delay to traffic waiting for a through phase. By reducing the cycle time below what might be normally be used, intersection delay can be reduced. The reduced intersection capacity of a less than desirable cycle length may be justified by the reduction in bus delay.
- Adjusting signal progression plans through a corridor to improve bus operations is a potential transit priority strategy. In the literature review, no specific examples of this form of priority were confirmed and it may be an area for further research and demonstration. It could consist of adjusting average progression speed or bandwidth to benefit bus operations. It would likely be most effective where the location of bus stops for local bus services was reviewed at the same time. For example, alternating nearside and farside stops through a coordinated set of signalized intersections is likely to improve bus travel times and some projects have shown this to be the case.

Passive traffic signal priority measures are usually easier and less costly to implement as compared to active traffic signal priority measures. However, they are less effective in reducing bus travel time and delay, due to the inability to respond to specific bus movements. Also, they likely have a greater detrimental impact on general traffic flow in most cases. They are likely to be most applicable where there is a situation with high volumes of buses or some unique circumstances. Passive traffic signal priority measures may serve as a starting point to initiate ongoing dialogue between transit and traffic staff to increase traffic signal priority for buses.

2.4.2 Active Traffic Signal Priority

Active traffic signal priority measures involve ongoing interaction between the traffic control system and transit vehicles that enable a real-time response to specific vehicles. This usually involves some form of bus detection and traffic control system response action. In general

the response is a modification to the normal signal timing according to a predetermined strategy. Some examples of active traffic signal priority for buses are as follows:

- * A special phase can be provided to accommodate transit vehicles. This could be a special turning phase or a transit only display for buses to bypass queued traffic. An increasing number of jurisdictions utilize the special transit signal display (the cigar signal) as previously mentioned. The special phase could be accommodated within the current cycle length or the cycle might be modified and later corrected by the traffic control system.
- * Modification of signal phases to accommodate specific buses is the most common active transit strategy. This can be achieved by extending a green phase to allow an approaching bus to clear the intersection on that phase rather than waiting until the next green phase. It can also be achieved by initiating an earlier green phase for approaching buses by truncating a side street green phase. This requires that minimum clearance time for side street vehicles and pedestrian crossings is provided. More advanced traffic control strategies could be used which modify the normal signal phases or modify the normal progression pattern through a series of intersections.

A more advanced form of active traffic signal priority for transit would be the integration of the traffic control system with a centralized automatic vehicle location and communications (AVLC) system for the transit vehicles. While this is a more recent development, there are some integrated systems now in use in European transit systems (2,3,4,5). Depending on the functional capabilities of the transit AVLC system and the traffic control system, this more sophisticated form of transit priority allows for a greater range of traffic control strategies to improve transit operations. For example, if a specific bus is running behind schedule, it could be given a greater priority than a bus that was on schedule or even ahead of schedule.

Another strategy is to adjust the normal progression pattern in a corridor to accommodate approaching buses. If the bus location can be tracked over a longer distance, this enables the traffic progression to be modified to better accommodate the bus without completely disrupting traffic progression.

A more advanced transit priority application would involve integration of a transit AVLC system with real-time adaptive traffic control systems. In London and Southampton, U.K. bus priority in the SCOOT traffic control system has been successfully implemented (4,5) and shown to provide improved operational results. SCOOT is a real-time adaptive traffic control system, developed by the Transport and Road Research Laboratory in the U.K., that uses vehicle detectors to measure traffic conditions on an ongoing basis and adjusts signal timing (splits, cycle and offset) to achieve the best possible traffic flow conditions. SCOOT has been modified to recognize buses and to give increased priority. The systems in London and Southampton utilize different system architecture and further testing and evaluation is ongoing to gain additional experience.

The integration of bus AVLC systems and Urban Traffic Control (UTC) systems is now being used in Europe and the results generally appear to be positive. This is likely to represent an upcoming stage of development in North America.

2.5 Operational Priority

In the ongoing operation of roadway facilities in an urban area, there are a wide variety of measures that can be used to provide buses priority over general traffic. For this report a few examples of some of these measures are described under the general heading of operational priority.

2.5.1 Bus Bays

The provision of bays on urban streets is sometimes utilized as a means of allowing buses to pull out of the regular traffic stream while stopping for passengers to board or alight. This arrangement facilitates the smooth flow of traffic while the bus is stopped. However, transit operators are then faced with the problem of maneuvering back into the traffic when leaving the bus stop. Some municipalities have investigated the provision of bus bays in more detail and developed policies that recognize the delays to bus operations and the overall passenger impact of bus bays. In almost all cases where the bus is stopping at a normal bus stop, the use of a bus bay has been found to cause an increase in overall passenger delay. As a result, there are examples of municipalities, such as Ottawa-Carleton, which have filled in bus bays as a means of improving bus travel time and schedule adherence. Generally, where the provision of bus bays has been investigated in more detail, it has been found that bus bays are only warranted in cases where buses have longer dwell times or there are specific safety concerns.

2.5.2 Bus Stop Bump Outs

On many streets with bus operations, the provision of curbside parking on either side of a bus stop creates the same effect as a bus bay. Buses stopping to drop off or pick up passengers are required to wait for a safe gap in the traffic stream to continue on from the bus stop. The use of bus stop bump outs is a measure to enable on-street parking to be provided without unduly interfering with the efficiency of the bus operation. An illustration of a bus stop bump out from Hamilton, Ontario is provided in Figure 2.10 below.

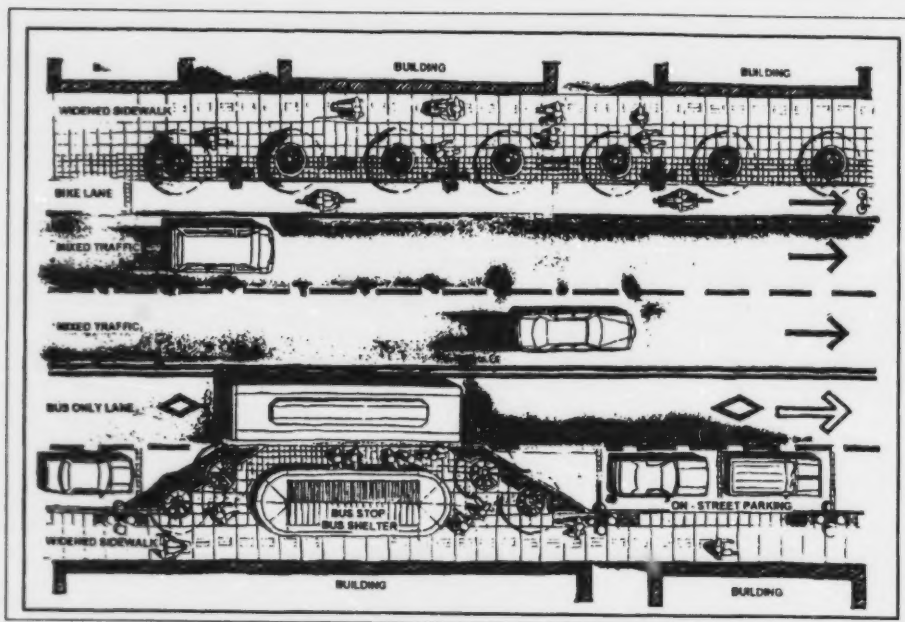


FIGURE 2.10: BUS STOP BUMP OUT (REF. 6)

2.5.3 Bus Turning Provisions

Public transit vehicles have larger turning radii and often are slowed down due to difficulties in maneuvering turns on crowded streets. The typical turning radius is in the order of 15 metres, which is sometimes difficult to accommodate on restricted downtown streets. A fairly inexpensive measure which has been used in some areas is setting back the stop bars on the streets the bus is turning from and turning into. By setting back the stop bars, stopped vehicles are less likely to obstruct the bus turning maneuver and bus operations can be improved. This is a very simple measure but it is a way to improve the transit services. An example of this particular technique is provided in Figure 2.11 below.

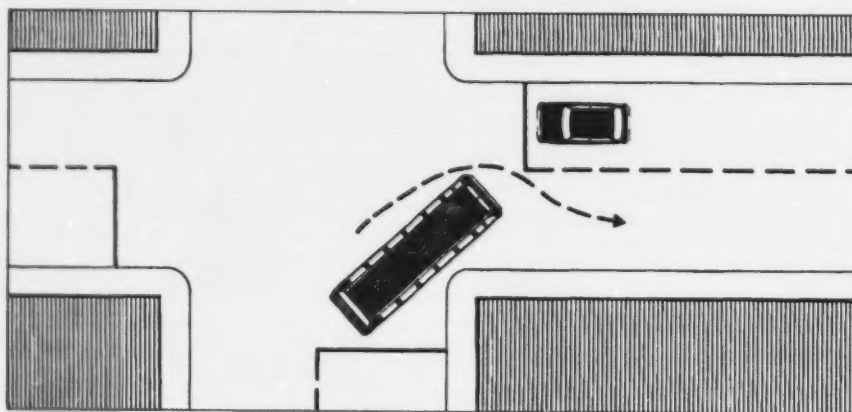


FIGURE 2.11: BUS TURNING PROVISIONS (REF. 1)

2.5.4 Bus Stop Parking Guidelines

On crowded urban streets with on-street parking, the arrangement of parking relative to the bus stop is critical to the efficient operation of buses. One of the reasons many transit systems use near-side bus stops is that the additional distance through the intersection makes it easier for the bus to move back into the through driving lane. One method of reducing the impact of on-street parking is the use of bump outs for bus stops as described in Section 2.5.2 above. Where this is not feasible, it is important to have guidelines in place that enable sufficient room for buses to pull into and out of the bus stops. Figure 2.11 below indicates the standards used in Hamilton, Ontario (6). These guidelines serve as a basis to ensure transit operations are given the appropriate priority in the allocation of curb space.

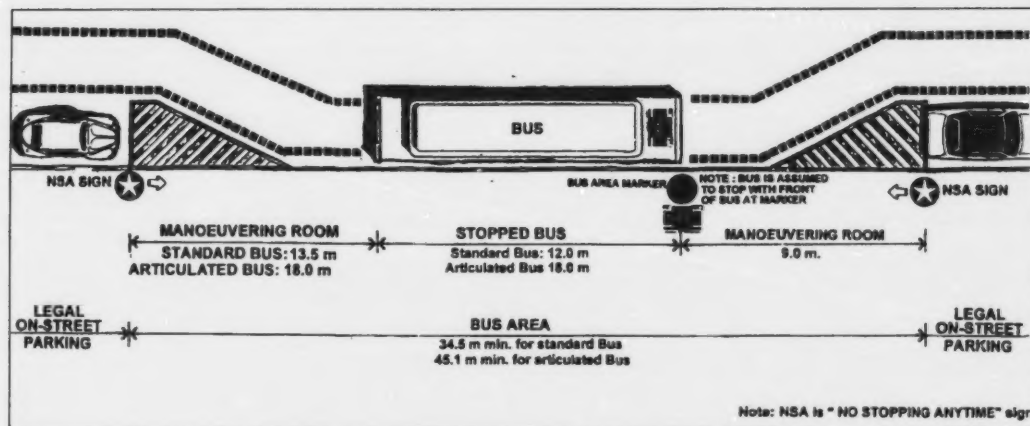


FIGURE 2.12: BUS STOP PARKING GUIDELINES (REF. 6)

2.5.5 Street Maintenance and Construction Coordination

Street maintenance and construction operations have significant impacts on public transit operations and services. The short-term nature of these events creates difficulty because insufficient time is available to redesign the service operation and notify customers. As a result the disruption of services is both costly and disruptive. There are many ways that these activities can be coordinated to provide priority to public transit. For example, many municipalities in Canada assign the highest priority to bus routes when clearing snow from the streets after a major snowstorm. This ensures that transit operations are least disrupted and it also enables more people to take the bus and reduce the level of vehicular congestion related to snow covered streets. Another form of priority is to provide higher standards of repair to curb lanes on streets used by public transit vehicles. By reducing the number of bumps and potholes in this lane, the buses can operate faster and provide a smoother ride to passengers. The coordination of major road repair and construction projects with transit services is a very important form of transit priority. This involves internal coordination

between the roadway and transit staff groups to ensure that projects are identified well in advance and provision is made to minimize the impact on transit services. It should be recognized as a form of priority that can provide significant benefits to the transit system.

2.6 Regulatory Transit Priority Measures

There are a number of ways in which priority can be provided to transit operations through traffic regulatory measures (7). These differ somewhat from the measures discussed in the previous sections in that they involve regulations as the primary means of providing priority to transit vehicles. A few examples of regulatory priority measures are described in the following section.

2.6.1 Transit Priority Signals

As previously discussed, a special transit priority signal display has been included in the Highway Traffic Act in Ontario and other similar displays have been regulated in other jurisdictions. The Ontario signal consists of a white vertical bar on a black background. Transit vehicles at an intersection facing a normal red signal display and the transit priority signal may proceed through the intersection while all other vehicles and pedestrians must stop and are not allowed to proceed through the intersection. The transit priority signal may also be used concurrently with other non-conflicting vehicular and pedestrian movements as directed by the traffic control signals. When the transit priority signal is not displayed, transit vehicles must obey the normal traffic signals. This signal is used in conjunction with specific passive or active traffic signal priority strategies. It is a relatively new development in Ontario but similar types of signals have been used in Europe for many years (1,2,3).

2.6.2 Priority Leaving Bus Stops

Traffic regulations in a number of European countries include specific provisions that motorists must yield to public transit vehicles leaving bus stops and attempting to pull into the continuous travel lane (7). The Provinces of Quebec and British Columbia have this as a traffic regulation in Canada and it has been considered in other Provinces. Ontario has initiated changes in traffic regulations but these have not yet been finalized. At least two states in the USA (Florida, Oregon) have passed legislation requiring drivers to yield to buses re-entering a traffic stream. In Quebec, motorists must yield to buses signaling to enter the traffic lane. The bus operator also has a responsibility to ensure they can enter the traffic lane without risk. Buses have a decal on the left rear panel reminding motorists of the traffic regulation. This regulation does not apply to buses entering or merging on a highway. A number of other transit systems in Canada use decals as a courtesy request (e.g., "Please Yield - Thanks") to assist bus operators in entering the traffic lanes.

2.6.3 Exemptions from Prohibited Turns

In many cities, providing buses an exemption from turn prohibitions at intersections is a method of providing transit priority which enables a more direct bus route or which may reduce travel time in traveling through a congested area. This is a fairly simple measure that can be implemented through traffic signs (e.g., "No Left Turns - Except Buses"). There are several variations on this exemption for buses that can be used in specific situations. These signing regulations have been found to be enforceable and have generally worked well after a period of familiarization.

2.7 Comprehensive Transit Priority Plans

In a number of European countries the planning of communities has included what can be loosely termed comprehensive transit priority plans. One view (1) of this approach is that traffic planning strategies to deal with increasing congestion in urban centres have evolved over time, generally as follows:

- First generation – planning to maximize traffic flow.
- Second generation – making special provision for public transit in traffic plans
- Third generation – comprehensive schemes which restrict vehicular traffic and favour public transit

A complete discussion of comprehensive transit priority plans is beyond the scope of this report. However, there are a number of features that have been incorporated into most of the plans, as follows:

- Bypass arterial routes around the central area have been developed to carry significant volumes of through traffic away from the city centre.
- Traffic cells are defined within the central area such that vehicular traffic may gain access to a particular cell but cannot travel directly from one cell to another. This prevents through traffic and reinforces the use of the bypass arterial routes.
- Parking facilities are strategically located to minimize the amount of travel within the central area. Also, the supply of parking is closely controlled to ensure that the needs for short term business oriented parking is satisfied while commuter parking is limited.
- The pedestrian circulation network is well developed and convenient to the public transit routes. Pedestrian-only streets may be designated, usually intersecting the major transit routes.
- Designated transit only streets or other similar transit priority measures provide a high level of accessibility into the city centre and good coverage for passenger service.

These comprehensive transit priority plans are usually part of a larger urban planning effort for a city and they involve a major commitment of time and funding. More importantly they involve a large commitment by the community to significant change. In the North American context, this type of major change and commitment to public transit and pedestrians over vehicular traffic would represent a major policy shift and one that would need clear public understanding and support to be successful. However, as urban traffic congestion continues to grow, consideration of these options will become increasingly necessary.

3.0 Traffic Engineering Considerations

Based on the findings from the literature review and the case study investigations, as well as this writer's experience, the development of successful transit priority measures requires a high level of traffic engineering. The most successful measures are those that provide significant operational improvements for transit vehicles without creating major safety or traffic flow problems. It has also been noted in CUTA's previous research (3) that most successful transit priority projects usually result from a close working relationship between transit staff, who are familiar with on-street bus operating conditions, and traffic staff with training and experience in traffic engineering. It has been noted earlier that there are many forms of transit priority measures and they tend to be innovative in nature. In developing innovative solutions to transit operating problems, it is helpful to have some general understanding of the broader range of traffic engineering considerations. The intent of this section is to provide the transit staff with some general information on traffic engineering considerations to assist them in working with their peers in the traffic section of the organization. It is intended as an overview only. For more information, the reader is referred to some of the references noted (8, 9, 10, 11, 12, 13).

3.1 Traffic Engineering Overview

Traffic engineering is a discipline of engineering that has evolved with the growth of motorized traffic in urban areas. Generally, traffic engineering is considered to be a branch of a broader transportation engineering discipline that would also include roadway design and construction, transportation planning, goods transportation and so forth. Traffic engineering within an urban context is primarily concerned with two objectives, as follows:

- Provision of smooth, convenient flow of vehicles, pedestrians and goods, often referred to as mobility and accessibility.
- Ensuring the safety of pedestrians, vehicles and passengers.

There are a variety of activities conducted on an ongoing basis within most traffic engineering organizations. These generally include:

- Providing appropriate traffic control through traffic signals, signs and pavement marking.
- Traffic regulatory control to establish appropriate regulations and to ensure compliance.
- Traffic monitoring through collection of data on conditions and specific situations.
- Studies of problems or conditions to determine need for improvements.
- Maintenance of traffic control equipment.
- Street lighting is sometimes provided through the traffic engineering organization.
- Traffic engineering may include the management of on-street and off-street parking operations.

As in most areas of the transportation field, the focus of traffic engineering activities continues to change and evolve to meet the changing needs in our communities. Provision of priority for public transit would be one example of an emerging traffic engineering

activity, in response to the need for improved efficiency and level of transit services in congested urban areas.

3.2 Traffic Safety

The safety of pedestrians, passengers and vehicles is an important component of traffic engineering. The various standards used in the design of roadway facilities and in traffic engineering practice have been developed from special studies and experience to ensure acceptable levels of safety. Safety, in terms of the risk of personal injury or property damage, is related to several factors:

- ✧ Driver characteristics
- ✧ Pedestrian characteristics
- ✧ Vehicle characteristics
- ✧ Road conditions
- ✧ Environmental conditions

The driver and pedestrian characteristics determine the key responses of perception and reaction that characterize human behaviour in different situations. These characteristics vary widely among the population due to age, physical condition, experience and other factors. Human factor studies are conducted to provide standards and guidelines, for use in traffic engineering, that accommodate driver and pedestrian characteristics of most of the population. Examples of these standards would be pedestrian walking speeds for intersection clearance and the perception-reaction time used to determine safe stopping distances for vehicles.

Vehicle characteristics relate to both static and dynamic characteristics. The static characteristics include vehicle weight, length and turning capabilities, for example. The dynamic characteristics of vehicles include acceleration and braking, rolling resistance and curve resistance. These characteristics are important in the design of roadway facilities to ensure adequate road structure capacity, horizontal and vertical curves, grades, turning radii at intersections and so forth. Provision for buses in the design of roadway improvements is important due to special requirements for adequate lane widths, turning radii and pavement load capacity.

Road characteristics that impact safety are numerous and include most aspects of roadway design. This includes such things as sight distances, surface condition, physical layout of lanes and intersections and so forth. Roadway standards (12,13) for design and traffic signing have been developed to achieve desired safety levels.

The environmental considerations that affect safety include such factors as weather, lighting and adjacent activities. These factors cannot be predicted with absolute certainty so traffic engineering standards usually reflect the situation that would occur most of the time.

3.3 Traffic Flow Characteristics

Traffic flow theories are used to describe and analyze traffic conditions on different types of roadway facilities. There are two distinctly different conditions that need to be recognized, as follows:

- Uninterrupted traffic flows that occur on highway and freeway facilities. In these situations, the characteristics of the traffic flow are influenced predominantly by the geometric conditions of the facility. The analysis of traffic flow conditions is usually concerned with highway capacity.
- Interrupted traffic flows that occur on urban streets with controlled intersections. In these situations, the traffic flows are influenced predominantly by the characteristics of the intersections. The analysis of traffic flow conditions is concerned with intersection capacity.

A general overview of these two cases is provided in the following sub-sections.

3.3.1 Highway Capacity

The capacity of a highway facility is defined (9) as the maximum flow of traffic, expressed as vehicles per hour (vph), that can reasonably be expected to pass a specific point during a given time period under the prevailing conditions. The conditions that influence capacity include the following:

- Roadway conditions such as the number of travel lanes, lane and shoulder widths, lateral clearances and grades.
- Traffic characteristics such as the number of trucks, buses and other heavy vehicles, the distribution of traffic by direction and the experience of the drivers.
- Environmental conditions related to weather and light levels.

There are several elements of traffic flow used in highway traffic analysis, as follows:

- Volume refers to the total number of vehicles that pass a point on a roadway during a given time interval, usually referred to in vehicles per hour (vph).
- Flow is the equivalent hourly rate at which vehicles pass a point on the roadway, during some time interval.
- Density is the concentration of vehicles on a unit length of a roadway and can be referred to as vehicles per kilometer.
- Headway is the difference in time between the front of a vehicle and the front of the next vehicle to arrive at a fixed point, usually referred to in seconds. Headway may also be referred to as space headway, which is the distance between a vehicle and the following vehicle.
- Speed is the distance traveled by a vehicle during a unit of time, expressed in kilometers per hour. There are two different speeds referred to; namely, time mean speed and space mean speed.

The flow conditions on a section of roadway are usually described in terms of level of service. The Highway Capacity Manual (9) has developed a description of flow conditions, using six levels of service ratings. A precise definition of each level of service condition

involves a number of factors. However, to illustrate the differences, a simplified description for freeway situations is provided in Table 3.1 below.

Level of Service E is usually considered a roadway facility's capacity although this is also an unstable condition where the flow can "break down" and become a Level of Service F condition. For this reason, many authorities plan roadway facilities for Level of Service D conditions to provide some flexibility.

Level of Service	Typical Driving Conditions	Vehicle Speed (Km/hour)	Typical Traffic Volumes (vehicles/hour /lane)
Level A	Free flow	100 kph	700
Level B	Stable flow, few restrictions.	Up to 90 kph	1000
Level C	Stable flow, some restrictions.	Up to 80 kph	1500
Level D	Congested flow, restrictions on maneuvering.	Up to 65 kph	1800
Level E	Unstable flow, low speeds, some stoppages.	Varies, up to 65 kph	2000
Level F	Forced flow, low speed, many stoppages.	Varies, less than 50 kph	Less than 2000

TABLE 3.1: DESCRIPTION OF LEVELS OF SERVICE

Level of Service E is usually considered a roadway facility's capacity although this is also an unstable condition where the flow can "break down" and become a Level of Service F condition. For this reason, many authorities plan roadway facilities for Level of Service D conditions to provide some flexibility.

3.3.2 Intersection Capacity

On roadway facilities with controlled intersections, the level of service or flow conditions are determined by the performance of the intersections. Intersections may be controlled by traffic signals, stop signs or yield signs. In any event, the resulting performance is related to a wider variety of factors than is usually considered in highway situations. For example the interaction of the different traffic movements at the intersection (e.g., left turn movements conflicting with opposing through movements) and the timing of the traffic signals at the intersection have a significant impact on the operational performance.

The two references used by Canadian traffic engineers for the analysis of intersection capacity are the Highway Capacity Manual (9) and the Canadian Capacity Guide for

Signalized Intersections (11). While the basic theories and terminology in these two approaches are generally similar, there are differences in the methods of measurement and the calibrated relationships. The differences are beyond the scope of this document but it should be noted both methods are accepted as sound approaches to analysis of intersection capacity.

The capacity for an intersection can be defined for each approach and is usually described as the maximum rate of flow that can go through that intersection approach under the prevailing conditions related to traffic, roadway geometry and signal operation. Capacity is expressed as vehicles per hour. The concept of saturation flow is important in intersection analysis. It is defined as the flow rate at which vehicles waiting in a queue can be discharged during a green interval at a signal. This value typically varies between cities, with values of 1600 to 1950 passenger car units per hour of green (pcu/h) noted for Canadian cities (11). The actual capacity of an intersection approach, then, is the saturation flow times the ratio of effective green time divided by the total signal cycle time (referred to as cycle length). Effective green time is the length of time (in seconds) that vehicles actually travel through the intersection and is equal to the total green plus amber time on that approach, less the time lost at the start of the green phase and the unused time at the end of the following amber phase. The values used for saturation flow and effective green time are derived from measurements of traffic behaviour. A measure of performance for an intersection approach is the degree of saturation, defined as the actual approach volume divided by the capacity of that approach.

The analysis of the capacity of a signalized intersection approach involves several steps, including the following:

- The intersection conditions including geometry, signal timing and approach traffic composition are defined.
- Saturation flow is defined.
- The approach traffic volume characteristics are defined.
- The capacity analysis is carried out for each lane group and the approach.
- Approach performance is determined based on estimated average delay.

Both the references noted above (9,11) provide tables and charts to apply the required adjustments for specific conditions.

The analyses of capacity have traditionally used vehicles, or more specifically "passenger car equivalents" (pcu) to measure and express capacity. Other types of vehicles such as buses, trucks and so forth have a value for conversion to pcu's. This approach does not recognize the different passenger capacity levels of different types of vehicles such as cars and buses.

3.4 Traffic Signal Timing

Traffic signal timing is designed to determine that timing pattern which provides minimal delay at an intersection, ensures standards of safety for pedestrians and vehicular traffic and provides smooth, efficient flow of traffic. Some of the terminology commonly used in traffic signal timing is outlined below.

- ◊ Cycle or cycle length is the time period for one complete colour sequence of signal indications, usually expressed in seconds.
- ◊ Phase or signal phase is that part of a cycle allocated to a stream of traffic having the right of way.
- ◊ Interval is any part of the cycle length during which signal indications do not change.
- ◊ Yellow or amber clearance interval is the length of time provided at the end of the green phase for vehicles to clear the intersection.
- ◊ All red interval is the time of a red display to all traffic approaches to permit pedestrian or vehicles to clear the intersection before the next interval starts.
- ◊ Split is the percentage of the cycle length allocated to each phase.
- ◊ Progression is the time relationship between adjacent signalized intersections permitting a continuous flow of a platoon of vehicles through these intersections at a particular average speed.
- ◊ Offset is the time interval between the beginning of a green phase at an intersection and the beginning of the green phase at the next intersection.
- ◊ Controller is the device at a traffic signal installation that controls the signal phases and timing in accordance with a fixed or variable timing plan.

At isolated intersections, where the signal timing is not coordinated with other adjacent intersections, signal timing is concerned with the selection of appropriate phasing, cycle length, allocation of time to each phase and the provision of the required clearance intervals. The appropriate phasing is related to the geometry of the intersection and the traffic volumes on each specific movement. The cycle length is selected based on the number of different phases as well as an analysis of capacity required and vehicular delay. Cycle lengths typically range from 50 to 120 seconds.

On urban arterial roadways, the signal timing of adjacent intersections may be coordinated to provide continuous travel through a series of intersections, avoiding the need to stop at each intersection. A time-space diagram is shown in Figure 3.1 that illustrates the coordination of seven adjacent signals in a corridor to provide continuous vehicle flow patterns or progression. In this example, progression is achieved in both directions at average speeds of 25.9 miles per hour and 25.4 miles per hour, respectively. This figure also illustrates the concept of bandwidth, which is the time available in each green phase band for a platoon of vehicles moving at the progression speed. In the example in Figure 3.1 the bandwidth is 10.5 seconds in one direction and 11.2 seconds in the opposite direction. To obtain coordination along an arterial roadway, it is necessary for each signal to have the same cycle length. In the example in Figure 3.1, the cycle length that is used is 50 seconds.

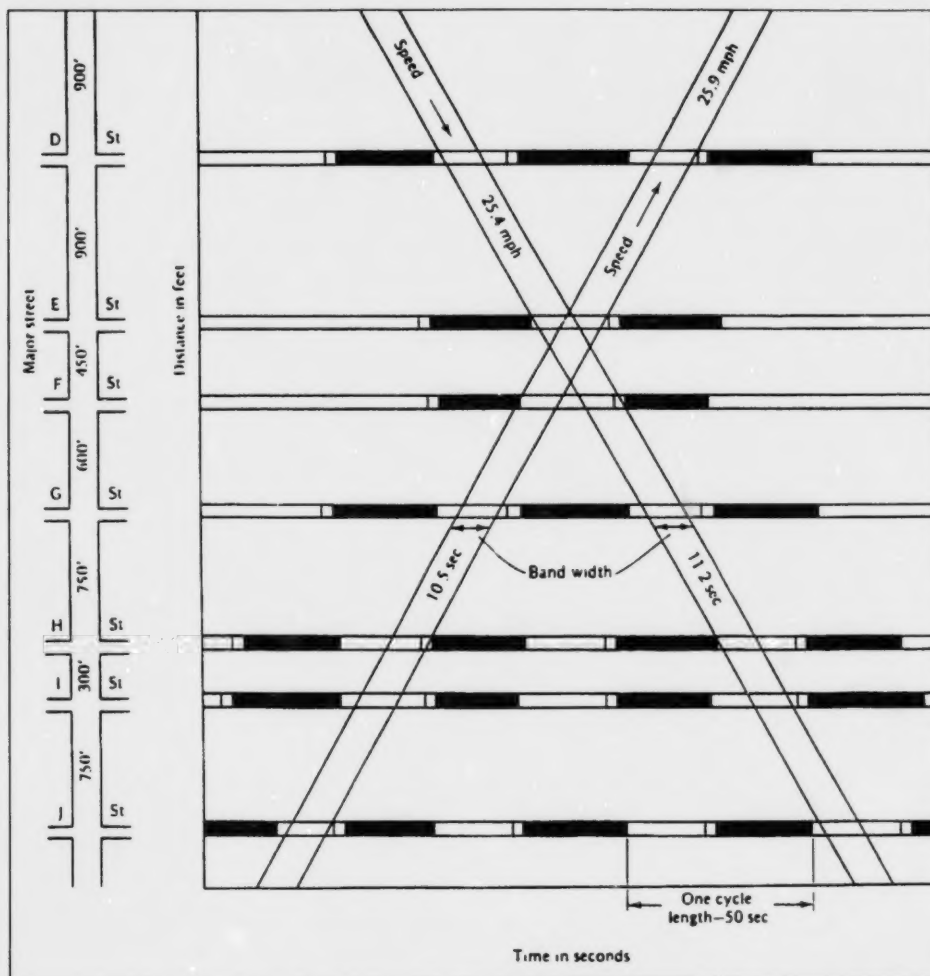


FIGURE 3.1: EXAMPLE TIME-SPACE DIAGRAM FOR TWO WAY STREET

The development of coordinated traffic signal timing plans is usually based on computer models to facilitate the simulation, optimization and analysis of traffic performance. There are a wide variety of models with different capabilities and this report only lists a few examples. Some of the models used as signal timing optimization tools are as follows:

- * MAXBAND (maximum band width) for determination of through band width in a series of signals.
- * PASSER and PASSER II (progressive analysis and signal system evaluation routine) which considers traffic demand in determination of cycle lengths and also optimizes phase lengths as well as arterial progression.
- * TRANSYT 7F provides optimization of signal timing in a coordinated network and also provides various performance measures. This model has the capability to recognize bus traffic as distinct from vehicular traffic.
- * AAP/M (arterial analysis package/microcomputer) is a package used to design and evaluate signal timing for arterial traffic signals.

- * SYNCHRO is a recent model package that performs capacity analysis, optimizes signal timing, provides time-space diagrams and can be readily interfaced with other packages.

Signalized corridor simulation models are useful to evaluate different proposals involving traffic signals or other aspects of an arterial street network. A few examples of simulation models are as follows:

- * TRAF-Netsim is a network simulation model based on a link-node simulation of a network that also includes signal timing and can simulate bus operations as well. It provides various performance measures for analysis purposes.
- * CORSIM is another microscopic traffic simulation model that can be used to simulate the performance of signalized networks.
- * INTEGRATION is a detailed simulation model that provides visual simulation of traffic operations and also provides some optimization capabilities.
- * SIMTRAFFIC is also a detailed simulation model that provides visual simulation of traffic operations and also provides some optimization capabilities.

It is noted that some traffic models have the capability to recognize and account for bus operations as distinct from mixed vehicular traffic. However, almost all signal timing models are based on optimizing "vehicle" throughput at signalized intersections as opposed to optimizing "person" throughput. In some of the more recent studies related to provision of transit priority, there has been some attempt to assess the overall person-carrying capacity of a signalized corridor. The implications of the greater person capacity of public transit vehicles on signal timing methods is an area that warrants further research and development.

3.5 Traffic Control Equipment

The implementation of transit priority at signalized intersections is dependant on the traffic control equipment that is used. A general description is provided in this section. The main components of the traffic control equipment at signalized intersections are outlined below.

- * Traffic signal heads contain the various lights or signal faces used to control vehicular and pedestrian traffic. The Manual for Uniform Traffic Control Devices (MUTCD) (12) provides specific standards relating to the signal displays at intersections to ensure safety and uniformity.
- * Traffic signal controllers control the operation of the signal displays in accordance with the signal timing plan for the intersection. There are a wide variety of traffic signal controllers in use. Older controllers utilized electromechanical equipment to achieve the necessary signal display control but newer controllers now use microprocessor technology and have much greater functional capabilities. For transit priority control strategies using bus detection, the controller must be capable of interfacing with the bus detection equipment to initiate a bus priority control plan. The control plan is then implemented through control logic provided within the controller.
- * Traffic detection devices are used with semi-actuated or fully actuated controllers to detect vehicle or pedestrian presence. There are a variety of detection technologies used but the most common technology is inductance loops embedded in the pavement and

- connected to detector amplifiers in the controller cabinet. These detectors sense the change in magnetic field due to the metal mass of vehicles passing over the loop.
- Controller interconnection is used to coordinate the signal timing at adjacent intersections. The interconnection may consist of electrical connections or data communication using various media. The connections may involve a master controller and several slave controllers or may also involve a central computer system that is used to coordinate traffic control and to perform other functions such as status monitoring.

Traffic controllers may be fixed time controllers, which means that the signal timing is fixed throughout the day or only changes at predetermined times of the day. There are also semi-actuated and fully actuated traffic controllers that can modify signal timing according to actual traffic conditions. Semi-actuated controllers are typically used where the side street demand is low and a green signal interval is maintained for the main street unless the side street phase is actuated. Fully actuated controllers provide the capability of variable cycle lengths and phase intervals in response to changes in traffic conditions. These controllers depend on detection equipment to monitor traffic on an ongoing basis.

3.6 Transit Priority at Traffic Signals

As will be noted in the case studies discussed in Chapters 4.0 to 8.0, the technology and control strategies used for transit priority at signalized intersections differ from one project to the next. However, it is possible to describe the general concept of how transit priority interfaces with traffic signals as a starting point for the discussion of the case study projects. Figure 3.2 provides a schematic illustration of a bus approaching a signalized intersection.

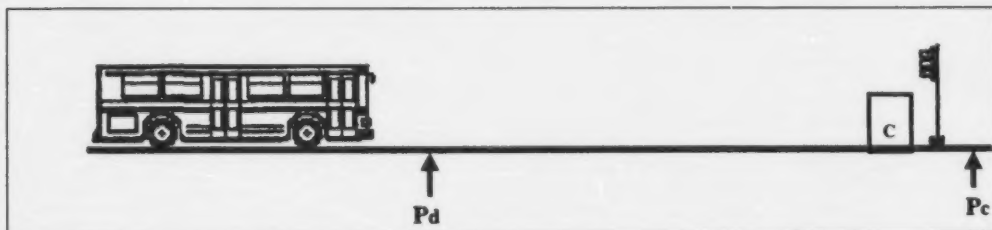


FIGURE 3.2: TRANSIT PRIORITY AT TRAFFIC SIGNALS

The general steps involved in providing priority are as follows:

- The bus approaching the intersection is detected by the bus detection system at some point P_d upstream of the intersection.
- The bus detection system communicates to the traffic controller C that a bus is approaching the intersection. The traffic controller initiates the bus priority logic to provide priority. Typically, if the intersection signals are already displaying a green phase for the approach being used by the bus, the controller will extend the length of the green

phase to enable the bus to pass through the intersection on that phase. If the intersection signals are displaying a red phase on the bus approach, the controller will shorten the green phase on the cross street (e.g., truncate the red phase) to provide an earlier green phase for the bus approach.

- * When the bus passes through the intersection, clearance is detected by the bus detection system **PC** and a communication is sent to the traffic controller that the bus has cleared the intersection.
- * On being notified that the bus has cleared the intersection, the controller **C** restores the normal signal timing through a predetermined logic.

There are many variations on this particular example. Some systems do not specifically detect bus clearance. Rather, the controller logic assumes that the bus will clear in a specified interval of time. The controller logic usually has specific rules in regards to the maximum green extension or red truncation times to limit the disruption to side street traffic or to ensure that a reasonable pattern of progression is maintained. The controller logic must also ensure that normal safety clearances are provided for vehicles and pedestrians in changing the signal displays. Also, in some cases, the modification of the signal timing is done in a manner that does not change the overall cycle length. In other cases the cycle length may be changed and is subsequently restored later by the controller. With traffic control systems that use a central computer to coordinate signal timing, the control logic also has to ensure that the control between the central computer and the intersection controller is not disrupted.

The design of the control logic used to provide bus priority must consider several factors, as follows:

- * All safety standards for pedestrians and vehicles must be maintained. For example this will limit how quickly a truncation of a red phase can occur to provide an early green phase.
- * The more quickly an earlier green phase is initiated, the greater the potential impact on the side street vehicular traffic.
- * The ability to detect the bus clearing the intersection, will enable normal signal timing to be restored more readily and will reduce the overall impact on vehicular traffic.
- * If the signal timing modification changes the normal signal cycle length, traffic progression along the corridor will be disrupted.

The development of control logic for transit priority must recognize these various factors and others in reaching a reasonable balance in providing improved operating conditions to buses while not creating significant traffic problems. The potential use of AVL systems offers the potential for much more effective transit priority control where the level of priority can be adjusted to reflect individual bus schedule status. For example, priority could only be given to buses behind schedule but they could be given a higher level of priority.

4.0 Toronto, Ontario Case Study

4.1 Introduction

Toronto, Ontario is Canada's largest city with a population of over 2.3 million people. The Greater Toronto Area (GTA) has a population of about 4.5 million people. The City of Toronto is located on the north shore of Lake Ontario with the downtown area located near the lake and the City is spread out to the north, east and west, continuing into the suburban Regions that form the GTA. The Toronto geography has relatively flat terrain, broken by several river valleys that run south to Lake Ontario. The road network in Toronto consists of roads and freeways generally oriented in a north-south and east-west pattern.

The persons who were contacted regarding Toronto's experience with transit priority were as follows:

- ✦ Mr. Gary Carr, Toronto Transit Commission, Telephone 416 393 4466, E-mail gary.carr@ttc.ca
- ✦ Mr. Les Kelman, City of Toronto, Telephone 416 392 5372, E-mail lkelman@city.toronto.on.ca

4.2 Transit System

4.2.1 Organization

The Toronto Transit Commission (TTC) is responsible for all public transit services operating within the City of Toronto and the Commission also operates some services outside the City under agreement with the adjacent municipalities. The Commission members, who act as a Board of Directors for TTC, are appointed by Toronto City Council and are all members of City Council. The Chief General Manager and staff of TTC report to the Commission.

The responsibility for administration of roads and traffic operations within Toronto rests with the City of Toronto Transportation Services Division. This includes the traffic control system for all signals within the city as well as operation of the freeways under City jurisdiction. The Provincial Ministry of Transportation (MTO) also has jurisdiction over several freeway facilities within City boundaries. As a result of policy changes at the Provincial level in the past few years, the MTO does not currently have any significant involvement in the provision of City transit or roads.

4.2.2 Services

TTC provides a comprehensive range of public transit services within the City of Toronto, including four heavy rail (subway) lines, an advanced LRT line (Scarborough Rapid Transit or SRT) and a number of LRT (streetcar) lines operating on both separated alignments and

in mixed traffic conditions. In addition, TTC provides an extensive bus service throughout the City. A number of TTC routes operate outside the City, serving adjacent municipalities and the Pearson International Airport that is located outside City limits. A separate public transit system (GO Transit) provides inter-regional transit service in and out of downtown Toronto, using both buses and commuter rail facilities.

The general configuration of the TTC services tends to be a grid network. The subway lines form the basic grid with one line to the north (Yonge Line), one to the northwest (Spadina Line) and a line running west and east from the central area (Bloor-Danforth Line). The bus routes generally tend to run on the main east-west and north-south arterials connecting to the major subway stations. In the inner area of the City, the streetcar lines are utilized to provide higher capacity services, again generally operating in a grid pattern utilizing the major streets.

The TTC has developed a Communications and Information System (CIS) that provides real time information to central control locations on vehicle location and characteristics. This system is currently operational on all streetcars but is not used to monitor and control bus operations.

An overview of Toronto's transit services is provided in the following table.

Toronto Transit Overview (1998)	
Fleet Size:	
Buses	1498
Light Rail Vehicles	248
Heavy Rail Vehicles	638
Other (SRT)	28
Total	2412
Annual Ridership	389 Million trips
Total Employees	9,935
Revenue Service:	
Revenue Kilometres	178,000,000
Revenue Hours	7,750,000

TABLE 4.1: TORONTO TRANSIT OVERVIEW (1998)

Persons using the Toronto transit system may pay their fare by cash, ticket or token or by monthly pass. Free transfers are provided between the different modes operated by TTC, enabling a trip to be made anywhere within the City of Toronto for a single fare.

4.2.3 Transit Operations Control

TTC employs its Communications and Information System (CIS), an Automated Vehicle Location and Control System, and on-street supervisors to monitor and adjust the operation of its surface transit services. Operators can monitor their schedule adherence via the CIS on-board display and can communicate with Transit Control via CIS special function keys, text or voice. Route supervisors monitor the operation of their assigned route(s) at strategic locations and can communicate with CIS personnel to assess overall route operations. Route supervisors can issue service instructions to individual operators as the vehicles pass by or via the CIS control room.

4.3 Traffic Control

The City of Toronto is responsible for the operation and maintenance of all roadway facilities, including traffic control signals within the City. Prior to a major restructuring of the local government structure, the Municipality of Metropolitan Toronto (Metro Toronto) was responsible for operation and maintenance of the arterial roadways and urban freeway within the same area and this included responsibility for the traffic signal control system.

Metro Toronto was one of the first cities to use a central computer to coordinate the control of traffic signals. There is a lengthy history of innovation and development with Toronto's traffic control system. At the present time, the Traffic Signal System Unit is responsible for the operation of 1842 traffic control signals within the City. Over 1800 of these signals operate under central computer control on one of the City's three traffic control systems. The City of Toronto developed its own traffic control system that provides control and monitoring capability for the majority of traffic signals in Toronto through fixed time plan operation. Real-time adaptive control has been implemented for a portion of the central area and a number of critical arterial routes. The City's traffic signal control systems and the number of traffic signals controlled by each (January, 2000) are summarized as follows:

* Main Traffic Signal System (MTSS)	1558 signals
* Siemens UTC V18.2/SCOOT V3.1	246 signals
* Econolite Aries	7 signals
* Total Computer Controlled	1811 signals
* Awaiting Connection	12 signals
* Isolated Operation	19 signals
* Total Traffic Signals	1842 signals

The MTSS consists of a PC-based cluster configuration with individual traffic controllers organized into cells. An interval control strategy is used by the MTSS with central cell control applying "stop time" to local interval controllers continuously. The communications are provided via leased data circuits connecting the central system with the intersection controllers. A large number of the controllers are over 20 years old and due for replacement. At present there are no linkages between the traffic signal control centre and the transit control centre.

4.4 Public Transit Priority

4.4.1 Policy

Toronto depends heavily on its public transit system with over 27% of peak hour trips by Toronto residents using the TTC in 1996. With this heavy dependency on public transit, there has been strong public support for providing good public transit service and ensuring that it remains an attractive mode of travel within the city.

4.4.2 Background

The current transit priority projects in Toronto were developed through a work program that has been jointly carried out by the staff of TTC and the Transportation Services Division (formerly of Metro Toronto and now of the City of Toronto). This work was started in the mid-1980's and resulted in a number of study reports and projects since that time. These reports addressed general transit priority measures in selected congested corridors, the development of a demonstration project on streetcar priority at signalized intersections on Queen Street West and development of a demonstration project on bus priority at signalized intersections in the Brimley Road corridor. These two demonstration projects have provided the basis for further applications of streetcar priority and, more recently, bus priority in other corridors.

4.4.3 General Transit Priority Measures

There have been a variety of general transit priority measures introduced during the past decade in Toronto to maintain and improve transit operations in areas of congestion. A few examples of some general measures are as follows:

- Prohibition of on street parking, on-street stopping, left turn movements and right turn in specific critical areas to improve bus and streetcar operations. This form of priority has been used in a number of areas where specific transit operational problems have been identified.
- Turn lanes signed for "right turns only - buses excepted". This has been used in several areas to enable buses to move through intersections with reduced delay or to enable vehicular traffic to use a designated bus only lane for a short distance.
- Traffic lanes designated as "bus only lanes". These have been utilized in a number of corridors such as Bay Street and Eglinton Avenue to provide improved bus operations through congested areas. Most bus lanes have been converted to HOV lanes to allow them to be used by vehicles with three or more occupants.
- Queue jump lanes have been developed at several intersections along Eglinton Avenue, westbound on Steeles Avenue E. at Don Mills Rd and westbound at Wilson Street at Wilson Station
- HOV lanes have been implemented on Dufferin Street/Allen Road, Yonge Street, Don Mills Road/Overlea Boulevard/Pape Avenue, Eglinton Avenue E and Dundas Street W. These lanes are designated for use by buses and carpools. Some enforcement problems

have been experienced but more recently efforts are being made to reduce the violation rates.

- Traffic signals are used to reduce delays to buses at Eglinton, York Mills and Downsview subway stations. Advanced detection is being used at a number of signalized intersections to reduce transit delays. The Provincial designated special transit signal phase (white vertical bar on a black background) is also being used at a number of intersections to provide priority to transit vehicle movements.

4.5 Traffic Signal Priority For Transit

There have been two specific demonstration projects implemented in Toronto that have served as the basis to evaluate traffic signal priority for transit vehicles and have also served as models for further development of transit priority. The first project was the Queen Street West Streetcar Priority Project that was implemented in 1990 and the Brimley Road Bus Priority Project that was implemented in 1995. These two projects were both developed as demonstration projects and detailed reports were prepared. Since they form the basis for further transit priority development in Toronto for both streetcar and bus priority, they are described in the following sections.

4.5.1 Queen Street West Streetcar Priority Project

Description

The Queen Street West corridor is a 1.6 km corridor between Bathurst St and Dovercourt Rd with six signalized intersections. It was selected for the demonstration project through earlier work, on the basis that:

- The intersections were not over saturated to the point that transit priority would create significant problems.
- The results in this corridor were felt to be readily applicable to other streetcar corridors.
- The Queen St streetcar route was experiencing poor operating conditions.

Queen St is an east-west arterial road with two-way streetcar operations in mixed vehicular traffic and generally with four traffic lanes. Eight hour daytime traffic volumes on Queen Street in this area are in the order of 7500 to 10,000 vehicles (both directions). The 501 Queen streetcar route operates through the downtown area with a 34 km round trip distance. Service headways are about 3.7 to 4.1 minutes during peak periods and about 5.5 minutes during weekday mid-day periods. Thirty four streetcars are used during peak periods and 24 streetcars are used during mid-day periods. There were 7 streetcar stops in each direction in the project corridor and almost all these stops are nearside stops. In Toronto, vehicular traffic must stop behind the streetcar when doors are open. This has a significant impact on vehicular flow. One of the cross streets in the corridor (Bathurst St) also has streetcar traffic while another cross street (Ossington Ave) has bus traffic.

Transit Priority Technology

The technology used in this project consists of 5 components, as follows:

- Active transponders located on the underside of each streetcar.

- * Receiver loops located in roadway between streetcar rails at two locations (request and cancel).
- * Interrogator unit, a hardware device used to interpret signals from the receiver loop.
- * Controller interface that controls the transfer of signal operational control between the central computer and the local controller.
- * Signal controllers modified to provide transit priority logic.

Two transponders were already on each streetcar to provide track-switching capabilities. The receiver loops were used to detect the radio signals emitted by the front transponder on the streetcars. One loop was located upstream of the intersection and provided the initial detection of a "request" signal from the streetcar. The second loop was located downstream of the stop bar at the intersection and acted as the "cancel" signal from the streetcar. The interrogator units were located in the traffic controller cabinets and connected by shielded cabling to the receiver loops. The controller interface was designed to accept the signals from the interrogator unit and to transfer signal control from the central computer to the controller or back to the central controller. The controller interface also provided certain failsafe capabilities. The signal controllers were programmed to provide the logic to provide the desired form of transit priority when a "request" signal is received. The technology selected was felt to represent the most cost-effective approach, recognizing the current technology available on the streetcars and the current traffic control system

Control Strategies

The system basically provided two forms of transit priority at each signalized intersection.

- * When a streetcar call is received during a green phase for Queen St traffic, the system could provide a green extension in increments up to a predetermined limit.
- * When a streetcar call is received during an amber or red phase for Queen St traffic, the system could provide a truncation of the side street green to provide an earlier green phase for Queen St.

These two strategies were implemented through logic in the local controller, after control had been transferred from the central computer. The control algorithm provides safeguards such as maintaining minimum pedestrian clearance times prior to truncating the side street green phase. The extent of the phase modifications at Bathurst St was reduced due to the heavier traffic on the cross street. When the streetcar clears the intersection ("cancel" signal), control is transferred back to the central computer that then restores the normal signal group coordination within a predetermined period of time. The algorithm used and the limits on the green extension and the red truncation were tested and finalized using a simulation package. Further testing in the field was conducted to ensure that the operations were acceptable.

Project Issues

The two main issues noted in the technical report on this demonstration project were technical issues, as follows:

- * Vehicle detection technology. The need to detect streetcars with a high level of reliability was recognized as a significant challenge. Three options were considered for the project, namely, detection using the TTC CIS (AVL) system, the active track switch control transponders and overhead contacts on the power supply line. The CIS system did not

have a sufficiently frequent polling interval to provide the necessary accuracy of detection and the overhead switch contacts would add to the visual clutter of overhead power lines. The active transponders were found to perform satisfactorily for vehicle detection purposes.

- Transit priority algorithm. A general algorithm with preset time parameters was used to provide the green extension or red truncation forms of priority. The parameters were the same in all controllers. Following the evaluation it was determined that more refined algorithms with specific features for each intersection would have been more effective. It was also found that the green extension form of priority was more effective than the red truncation.

Evaluation

The cost of the intersection equipment for the Queen St West demonstration project was reported as \$217,000. This includes all equipment and installation but does not include the planning, engineering and administration related to the demonstration. The largest component of this cost was the interrogator equipment and installation. It is likely that this cost could be significantly reduced with a larger application and refinement of the equipment itself. It is also noted that this cost does not include the transponder equipment that was already on the streetcars.

Following the initial operation of the demonstration a detailed assessment of the impact on transit and traffic operations was conducted. The main findings of this assessment are summarized as follows:

- Traffic signal delay for streetcars was reduced significantly through the demonstration section. Reductions in delay ranged from about 30 to 52 seconds (both directions) for different time periods.
- Travel time for streetcars was reduced significantly as well. Reductions ranged from about 22 seconds to 77 seconds (both directions) for different time periods.
- Transit passenger time savings were significant and were estimated to be approximately 30,000 person hours on an annual basis.
- Streetcar travel time variations were reduced through the area. The standard deviation of the travel times was reduced by between 18% and 73% depending on direction and time of day.
- The impact on vehicular traffic did not appear to be significant. The vehicular travel times along the corridor appeared to decrease by 1% to 13% in one direction and increase by 4% to 10% in the other direction. The side street signal delay did not appear to change significantly.

The results of the demonstration section were used to assess the feasibility of implementing streetcar priority on the entire Queen St route and it was estimated that it would result in a benefit /cost ratio of 1.63.

4.5.2 Brimley Road Bus Priority Project

Description

The Brimley Road bus priority demonstration project is located on Brimley Rd, between Steeles Ave and Sheppard Ave, in the northeast area of the City. Brimley Rd is a four lane

arterial road, typically with an additional left turn lane at the major intersections. The demonstration section is about 4.3 km in length with 10 signalized intersections. It has five local bus routes operating along the demonstration section with peak hour bus volumes of about 12 buses per hour in each direction. There are 37 bus stops (both directions) within the corridor, with about 75% of these being nearside stops. Four of the cross streets have bus service and three of these have significant volumes. This corridor was selected for the demonstration after an extensive investigation of a suitable location for a bus priority project. Brimley Rd met the various criteria established and was felt to be very typical of traffic conditions in other parts of Toronto. Also, it is significant that all bus routes operating on Brimley Rd use buses dispatched from the same operating garage.

Transit Priority Technology

An extensive investigation of possible technologies was conducted for the Brimley Rd project. Through this assessment, the technology chosen for the project was infrared transmitters installed on the side of the buses, receivers mounted on street poles adjacent to the roadway and radio frequency technology to transmit the detection signal to the signal controller. Two receivers were utilized to detect the bus entering the priority operation zone and leaving this zone. For receivers that were closer to the cabinets, a hard-wired link was used instead of radio frequency transmission. Four crossing streets had bus routes and these were also equipped for bus detection in a similar manner. The form of system detection – controller interface is not described so it is not clear if the same configuration is used as with Queen St.

Control Strategies

The control algorithms developed in this project utilized both main street green phase extensions and side street green truncation control strategies, generally similar to the Queen St control strategies. The algorithms were customized to three different types of intersections in the corridor by establishing different limits for the green extension and pedestrian protection displays. This helped to provide operations that better suited the conditions at each of these intersections. The operation of the signal is transferred to the local controller when a bus is detected and transferred back to the central computer when the bus has cleared the intersection in a similar manner as the Queen St project.

Project Issues

The technical report on this project discusses a variety of specific issues involved in the design and implementation. Some of the primary issues appeared to be:

- The infrared detection system required a number of adjustments to the height and setback of the receiver units. Some problems are apparently not fully resolved with the detection system. The study conclusions suggest that other forms of bus detection technology should be further assessed.
- An outstanding issue noted in regards to the transit priority algorithm relates to the pedestrian "don't walk" displays at intersections with transit signal priority. While the Brimley Rd project did not appear to have a significant impact on pedestrian delays at signalized intersections, this was an area identified for further investigation.

- It was not clear if the results of this project would be directly applicable to other corridors and this was an area of some disagreement. The staff involved recommended a further pilot project on another corridor to confirm the benefits assumed in the benefit/cost analysis.

Evaluation

The cost of equipment procurement and installation for the project (10 intersections) was \$355,000. This does not include the engineering and administration costs of the demonstration project.

Transit round trip travel time reductions through the corridor were estimated as 34 seconds in the AM peak, 84 seconds in the mid-day and 69 seconds in the PM peak. Transit delay reductions, on a round trip basis were estimated as 61 seconds in the AM peak, 76 seconds in mid-day and 78 seconds in the PM peak. Delays to transit vehicles on the cross streets were also estimated to have been reduced.

The impact on vehicular traffic traveling along Brimley Rd was generally positive. The average delay in different time periods and directions was either unchanged or was reduced by up to 17 seconds (15% reduction). On the cross streets the impact varied. For one intersection with high volumes of crossing bus traffic, the combined average delay decreased by 2% to 8%. However, on other cross streets the average delay to vehicular traffic was generally increased. An evaluation of pedestrian delay was also conducted but the results were not felt to clearly indicate a significant impact.

4.6 Other Developments

The results of the Queen Street West streetcar project have lead to an expansion of transit priority along the Queen St line and other major streetcar lines. There are currently over 130 signalized intersections on five streetcar routes that have been equipped with transit priority. While the priority algorithms at most intersections employ only main street green extensions and side street green truncations, more complex algorithms allowing multiple phase extensions, the use of the special transit signal display and various other control strategies have also been implemented. These developments are based on the experience gained through the initial projects.

One of the outcomes of the Brimley Rd bus priority project was development of a series of recommendations for application of transit priority in other corridors. While there did not seem to be full agreement on the overall applicability, specific recommendations were provided regarding a transit priority project on Dufferin Street. This project was completed in 1998. Six intersections of Sherbourne Street were equipped with transit priority in conjunction with implementation of bicycle lanes in that corridor. A further bus priority project on Bathurst Street is planned for implementation in 2000.

4.7 General Assessment

The development of transit priority measures in Toronto has been ongoing for over 15 years at present and there has been a great deal of experience and knowledge developed. The Toronto transit system is a very large operation and the services are heavily utilized. Similarly, the road network experiences "big city" congestion and a sophisticated traffic control system is utilized to provide safe and effective traffic operations. Developing transit priority measures in this environment is challenging from a technical and institutional point of view. However, a number of measures have been developed and implemented. The results from the two demonstration projects have been very positive in terms of:

- Significant transit operational improvements have been achieved without creating related traffic problems. This has resulted in overall travel time and delay savings for transit customers and the traveling public in total.
- In the case of the streetcar priority measures, there has been sufficient travel time savings to reduce the number of vehicles needed to provide service and hence lower transit operating costs have been realized.
- The experience has enabled further improvements in transit priority technology and control strategies. Increasingly complex algorithms are being used to reflect specific transit and traffic operating conditions at individual intersections and signal priority is increasingly being used to reduce delays to intersections at individual problem intersections.
- Signal priority is viewed as the most cost-effective transit priority measure used in Toronto. The signal delay reductions speeds up services and benefits transit customers. Furthermore, with less delay, priority equipped routes can maintain passenger capacity with fewer vehicles. The six routes equipped to date are reported to generate net annual operating cost savings of over \$1.25 million alone and all had a payback period of less than 4 years. In addition, 10 fewer streetcars and 2 fewer buses are required on these routes.

5.0 Ottawa, Ontario Case Study

5.1 Introduction

Ottawa is Canada's Capital City and together with the surrounding urban area and the adjacent Outaouais Region in Quebec forms the National Capital Region. The urban area of the Region of Ottawa-Carleton has a population of about 650,000, located on the south side of the Ottawa River. The central area of the City is located near the River and generally around the Parliament Buildings. The City of Hull and the remainder of the Outaouais Region are located immediately across the River in Quebec with several bridge connections. The economy in Ottawa is based on federal government services and a growing technology development industry. The main urban area of Ottawa is surrounded by a designated "green belt" and urban growth is now occurring outside the green belt.

The persons who assisted in providing information on Ottawa's experience with transit priority were as follows:

- * Mr. Kornel Mucsi, Region of Ottawa-Carleton, Telephone 613 560 2111 (Ext 3032), E-mail mucsiko@rmoc.on.ca
- * Mr. Brian Millar, Region of Ottawa-Carleton, Telephone 613 560 2111 (Ext 3192)
- * Ms. Helen Gault, OC Transpo, Telephone 613 842 3636 (Ext 2435), E-mail gault@octranspo.com

5.2 Transit System

5.2.1 Organization

The Ottawa-Carleton Regional Transit Commission (OC Transpo) is responsible for the operation of all public transit services within the designated Urban Transit Area of the Region of Ottawa-Carleton. The Commission, which is responsible for directing the affairs of OC Transpo, consists of elected members of Regional Council and is appointed by Regional Council. Management of the organization is the responsibility of a General Manager who reports to the Commission. Although OC Transpo is a separate Commission, it tends to operate much like other Departments of the Regional Municipality and there are close working arrangements between the Commission and the various Regional Departments.

5.2.2 Services

OC Transpo has followed a unique format in developing and upgrading the transit system over the past two decades. The upgrading of transit services has utilized transitways (exclusive bus-only roadways) as a means of providing transit service offering higher capacity and levels of service. The transitways typically consist of a two lane roadway with stations at selected locations to provide passenger access and connections to local bus routes. Local bus

services may connect at stations with express bus services traveling along the transitways or may access the transitways to operate express to the central area. Articulated buses are used on the transitways to provide greater capacity. In the central area of the City, exclusive bus lanes are used for downtown transit circulation. There are currently three transitway routes in Ottawa, comprising over 30 km of transitways, and the municipality plans to continue the development of the system with a connecting transitway through the central area and further expansion of the transitway network in several corridors. A number of roadway corridors have also been identified as transit priority corridors in the Region's Official Plan.

OC Transpo's bus service tends to have a radial pattern, focusing on the central area of the City. However, some of the transitway stations are located at major employment and commercial activity centres outside the City core. An overview of Ottawa's transit services is provided in the following table.

Ottawa Transit Overview (1997)	
Fleet Size:	
Standard Buses	671
Articulated Buses	114
Small Buses	9
Total	794
Annual Ridership	65 Million Trips
Total Employees	1,965
Revenue Service:	
Revenue Kilometres	34,200,000
Revenue Hours	1,377,000

TABLE 5.1: OTTAWA TRANSIT OVERVIEW (1997)

Persons using OC Transpo may pay for the service by cash, ticket or monthly pass fare media. A single fare provides a complete trip anywhere within the urban transit area. However, there are premium fares charged on express routes during the peak periods. OC Transpo has interconnecting service arrangements with the Societe de Transport de l'Outaouais (STO) which provides services in the Outaouais Region across the river from Ottawa.

5.2.3 Transit Operations Control

OC Transpo has a control centre that is utilized to maintain operational supervision of the bus services. The primary control responsibility rests with the operator who utilizes a trip schedule to keep the bus operating on-schedule. Two way radio communication is provided between the operator and the control centre to assist the operator in dealing with problems. At main transitway stations there are supervisors on duty to assist with operational problems as well as other customer service duties. Video surveillance has been installed at transitway stations, primarily for customer security. OC Transpo is currently in the process of developing an Automated Vehicle Location (AVL) system. Also, a link is being established

with the Traffic Control Centre to provide the Transit Control Centre with access to the video surveillance of critical traffic areas to assist on-street transit operations.

5.3 Traffic Control

The Regional Municipality of Ottawa-Carleton administers the traffic control system throughout the Region. The Traffic Signals Branch of the Region has responsibility for design, installation maintenance and operation of all traffic control signals. There are 876 signalized intersections within the Region and approximately 85% of these are controlled by six PC-based traffic control systems through the Control Centre. One computer at the control centre functions as the central controller and the other five are located in the field, controlling groups of signals. The central PC also functions as a common clock so that signals on different systems can be synchronized. There are also 27 locations monitored by closed-circuit television from the Control Centre. A communications connection is planned with the Transit Control Centre to provide access to this video surveillance.

5.4 Public Transit Priority

5.4.1 Policy

Ottawa has a relatively high level of public transit use, compared to other North American cities of a similar size. About 15% of peak hour trips currently utilize public transit. The Region's Transportation Master Plan and Official Plan, which were approved in 1997, emphasize continued efforts to increase the share of peak period trips that use public transit. A target has been set of 20% of peak period trips using public transit by year 2021. The Official Plan defines a transit priority network and specifically calls for the implementation of transit priority measures such as traffic signal priority and bus lanes, where required to maintain a reliable and competitive transit service.

5.4.2 Background

Most of the current transit priority measures have followed the establishment of a Transit Priority Task Force (TPTF) in 1994. This task force consisted of staff from the Region's Environment and Transportation Department, the Planning and Development Approvals Department and OC Transpo. The task force was given the mandate of investigating, implementing and evaluating transit priority measures. Since 1994, staff have been added within the Traffic Signals Branch to work specifically with the task force on transit priority projects. The approach has been a very pragmatic one with ongoing suggestions from OC Transpo operators, the task force members, and the general public providing the basis for identification of candidates for transit priority. A wide variety of measures have been developed and implemented since that time.

5.4.3 General Overview of Transit Priority Measures

Descriptions are provided below for some of the major transit priority projects developed by the task force since 1994. These descriptions do not include transit priority measures that are specifically part of the transitway system.

Bus Lanes

Bus lanes (with flow) have been added to the shoulders of Regional Road 174 as an extension of the transitway to the east (Blair Rd to Place d'Orleans) and Highway 417 as an extension of the transitway to the west (Moodie Dr to Eagleson Rd). In both cases these roadways operate as full access-controlled freeway facilities. The bus lanes are in effect for 24 hours per day. Peak hour bus volumes are about 100 buses per hour on Regional Road 174 and about 45 buses per hour on Highway 417. Although specific results are not available, these lanes have reportedly worked well in reducing bus travel times and improving schedule reliability. At the interchanges, special ramp connections have been utilized (see description below).

Bus lanes have also been established during weekday peak periods on Rideau St and Montreal Rd in the inner area of the City. These roadways are major arterials with high volumes of buses and existing lanes were designated for bus-only operations to reduce bus travel time and delay. Bus volumes are about 100 buses per hour in the peak period on the Rideau St bus lane.

Transit Ramp Connections

On the freeway segments with designated shoulder bus lanes, a number of ramps have been modified at interchanges to allow buses to exit on the off-ramp and to re-enter on the on-ramp of the freeway. This arrangement enables the buses to make connections with buses on the cross-streets and it also enables buses to bypass congested areas on the freeway. In one location, this arrangement is used in conjunction with a "demand for service indicating system (DSIS)" which enables waiting customers to push a button to signal the operator of the bus traveling on the freeway that they wish to be picked up. An illustration of the transit ramp connection configuration was provided in Figure 2.9 earlier.

Bus Queue Jump Lane

A bus only lane of approximately 550 metres in length was implemented on a heavily congested section of Woodroffe Ave, a major arterial in the west end of the City, by designating an existing mixed flow lane as bus only use. The lane continues through two signalized intersections, allowing buses to bypass the primary area of vehicular congestion. This area has very heavy bus volumes of about 45 buses per hour during peak periods. The queue jump lane has reduced bus delay by about 30 to 60 seconds, per bus, during the morning peak hour.

Another example of a bus queue jump lane is an advanced stop bar at a signalized intersection of Albert St and Empress Ave in the central core of the city. The advanced stop bar enables buses approaching in a bus only curb lane to bypass mixed traffic waiting at the

advanced bar in order to have first priority on proceeding through the intersection. This arrangement is illustrated in Figure 2.6 earlier.

A third example of a queue jump lane is a curb lane left turn for buses at an intersection of a minor arterial with a major arterial road in the west end of the city. In this case, the minor street has two lanes approaching with the left lane designated "left turn only" and the curb lane used for right turning traffic (There is no through movement). The right turn lane is signed as "right turn only – buses excepted" which allows buses to make a left turn from the curb lane. Since the left turning lane often backs up, buses are able to avoid most of the delay normally associated with this turn. The arrangement ensures that the bus can clear the intersection within the cycle.

Bus Bay Closure

On one fairly congested arterial road, there were a number of bus stops with bus bays that required buses to pull out of the curb lane to pick up and drop off passengers. On this route, there was a recognized problem of schedule adherence that was attributed in part to traffic congestion along the route. At the stops with bus bays, the bus stop time was relatively short but a considerable amount of time was often spent in maneuvering the bus back into the regular traffic stream. Six of these bus bays were filled in with the buses making their stops directly in the curb lane. While this created some delay for general traffic in the curb lane, there was a substantially greater delay reduction for the transit passengers and schedule reliability was improved.

5.5 Traffic Signal Priority For Transit

As noted earlier, the Region's Traffic Signals Branch and OC Transpo have had a task force established since 1994 with a mandate to develop and implement transit priority measures where warranted. The general approach has been based on identifying problems and then initiating an investigation in each case to determine whether some form of transit priority would be beneficial. In many cases it was found that the measures investigated would not provide a sufficient improvement to warrant implementation and these locations were not pursued. In cases where transit priority was felt to offer significant potential of overall improvement, the measure was implemented and the performance was monitored following implementation. For the most part, the measures have generally been specific to one intersection. Unlike most of the other Case Study cities, transit priority in Ottawa has tended to be a fairly large number of measures customized to the circumstances at particular locations. For that reason, the description is more general and tends to describe "typical" priority measures.

5.5.1 Traffic Signal Priority Projects

A description of some typical traffic signal priority projects is provided below.

Signal Priority for Side Street Buses

At eight signalized intersections, signal priority is being provided in response to bus detection on a side street approach. Typically, this is used to provide priority for buses making through movements or left turns from a side street on to a main street. Bus volumes are typically in the order of 6 buses/hour in the peak period. Detection of the buses is by loop detectors in bus-only lanes or other forms of detection where buses are using mixed traffic lanes. Detection of a bus results in a green phase extension or red truncation to provide the desired bus movement. Monitoring of these locations to date indicates that average delay savings of about 10 to 25 seconds per bus are being realized.

Transit Priority Signal Indicator (TPSI)

The Province of Ontario has revised traffic signing legislation to create a transit only signal display. It consists of a vertical white bar or "cigar signal". Ottawa has utilized this display at one location to enable buses to advance while other traffic is being held. Approaching buses are detected by a pair of inductance loops in the pavement that check for a longer vehicle length. Buses are then given the Transit Priority Signal Indicator (TPSI) display that allows them to advance ahead of the general traffic queue. Following the TPSI phase, the general traffic is allowed to advance on a normal green phase. The TPSI display is only used when buses have been detected.

Bus Actuated Half Signal

Several Ontario municipalities have introduced so-called "half signals" which are used to enable pedestrians to activate a green phase to cross a main street. Until activated, the signal provides the main street with a green phase for through traffic flow. Since pedestrian use is usually fairly infrequent, there is minimal delay to the main street traffic. This concept has been extended in Ottawa with the addition of transit detection to activate a side street phase to enable buses to turn onto the main street. Detection of the buses on the side street is by a pair of detector loops that are spaced to detect bus length vehicles. Trucks or other long vehicles can also activate the loops but due to the nature of the side street traffic this doesn't happen very often.

Two Bus Phases within Cycle

At three locations, signal timing plans are used which can provide a second green phase within a cycle in response to bus actuation. There are two ways in which this is achieved. In the first case, there are two phases available for the same movement within the cycle. If a bus is not detected, the time is used within the normal coordinated phases. For the second case a newly developed controller algorithm is used which can display the transit priority phase twice in the cycle and also can display it sooner than in the first case. In this case, the cycle length may be extended and it would then be restored by the central computer within the next cycle.

Other

In addition to the foregoing measures a number of other transit priority measures at signalized intersections have been tested and utilized to some extent. A few examples include the following:

- Use of left turn arrow displays for buses only.
- Using cycle lengths which are half the cycle length of adjacent intersections to reduce transit delay at that location.
- Operating signals on a stand-by mode in order to provide immediate response when a vehicle is detected.
- Modified signal timing (offsets) in the downtown area to better accommodate transit operation on the main downtown corridor.

5.5.2 Bus Detection Technology

Ottawa has used several different technologies to detect buses approaching priority control areas. In locations where there was a bus-only lane they have utilized conventional traffic detector loops since any vehicle detected is likely to be a bus. In a number of side street approaches, they have utilized a pair of detector loops, spaced such that concurrent occupancy indicates a longer vehicle (i.e., a bus). Since the particular streets have little or no truck traffic this has also worked reasonably well. In mixed traffic situations they have utilized overhead ultrasonic detectors that check vehicle profiles as a method of detecting buses. While these detection technologies have been more readily adaptable, the reliability and accuracy of detection in mixed traffic situations may be less than desired. Also, Ottawa does not yet utilize detectors to check for intersection clearance as is done in some areas. This limits the control strategies that can be used.

5.5.3 Traffic Control Strategies

Ottawa utilizes a variety of traffic control strategies as indicated in the previous sections. These include passive forms of transit priority such as signal progression timing (i.e., offsets) that are designed to better accommodate buses, modified cycle times (e.g., half cycle times) and special bus-only phases (activated by bus detectors) to accommodate bus movements at certain intersections. There are also a variety of active forms of priority that utilize bus detection and traffic control plans to respond to the bus detection. The strategies vary considerably at each location, depending on the particular circumstances. The general strategy, however, can probably be best described as a commitment to providing improved bus operation and service where this can be achieved without risking public safety or causing major traffic disruption.

5.5.4 Evaluation

A number of specific installations in Ottawa have been evaluated and shown to reduce bus delay and to improve schedule adherence. In most cases the evaluations have been in the form of follow-up monitoring of the installation to ensure that it is working as intended or to see if further fine-tuning is required. Since the installations tend to be isolated locations, evaluations are limited to those specific sites. The transit priority applications vary by type and location and it is difficult to assess the impact on overall bus requirements and operating costs. The exception to this would be the bus lane projects, which have high volumes of buses and enable significant operational improvements compared to mixed traffic. The Ottawa approach has been based on making changes at specific locations to respond to problems and to make transit priority an ongoing part of good traffic management. This has resulted in a whole variety of measures at over 30 locations since 1994. The majority of these

installations have improved transit operations without creating significant traffic problems. Where problems have occurred, they have been addressed and resolved in a practical way. Also, it should be noted that transit priority at signals is viewed as only one way to address operating problems.

5.6 Future Development

The Region of Ottawa-Carleton is committed to continuing the development of transit priority measures as part of its overall transportation strategy. There are a number of projects currently in the planning phase and specific problems are being considered on an ongoing basis. Future roadway design plans are reviewed by the Transit Priority Task Force and priority measures are included in the design, where possible. A major transit priority corridor project is planned for the Woodroffe Ave corridor, which will include construction of bus-only lanes as well as signal priority for buses. Since a corridor is involved, this project may involve more complex traffic control strategies and better forms of bus detection. The Region is currently investigating bus transponder technologies to achieve a more accurate and reliable method of bus detection. Also, further research is being conducted to develop more refined transit priority algorithms. There are also several locations currently in the planning and design stage for a queue jump lane at an intersection. A number of locations are under analysis for transit priority at signalized intersections and for TPSI installations.

5.7 General Assessment

There are several aspects of Ottawa's approach to transit priority that are noteworthy, as follows:

- Transit priority is being implemented as part of a broader strategy to increase the use of public transit in the community. There is a strong policy commitment to this goal at the elected representative level and it has been reflected in the Region's transportation Plan and Official Plan.
- From the outset, transit priority has been a joint effort at the staff level involving traffic, planning and transit staff. Further, the design and implementation has been the responsibility of traffic staff with transit staff providing input on on-street problems.
- The approach in each specific case has been to conduct a technical investigation and focus on whether a workable priority measure can be developed which will improve transit operations without creating major problems for other users of the road space.
- There appears to be a willingness to take risks and to learn from the experience gained through specific implementations.

Ottawa has not conducted as much research into technology for transit priority at signalized intersections as some other jurisdictions. In the initial stages the emphasis has been on utilizing off-the-shelf technology and keeping the technology fairly simple. This has worked well to date. With new control algorithms, however, a more reliable and accurate form of bus detection would be desirable. This is currently under investigation by the Task Force. Particularly, in using the TPSI signal phase, it is felt that it is important that it is only displayed when buses are available to use it.

6.0 Cermak Road (Suburban Chicago) Case Study

6.1 Introduction

The Cermak Road Transit Priority Project is located in three communities of suburban Chicago (Cicero, Berwyn and North Riverside). This project was a joint effort of a number of agencies, namely PACE Suburban Bus (PACE), Chicago Transit Authority (CTA) and the Illinois Dept of Transportation (IDOT).

The Chicago metropolitan area is one of the major urban centres in the USA with a population of over 7.5 million persons. The metropolitan area consists of the City of Chicago, six counties and numerous smaller municipalities that collectively make up the greater Chicago area. The central business district is located on the shore of Lake Michigan and the urban area is spread out to the north, west and east. The municipalities of Cicero, Berwyn and North Riverside are located about 6 to 12 miles west of the downtown area along Cermak Road. . Each community is a suburban municipality with a mix of single family and multi-family residential as well as commercial /business development.

The persons who were contacted regarding the Cermak Road project were as follows:

- ◁ Mr. Bob Huffman, Pace Suburban Bus, Telephone 847 228 2420, E-mail Robert.Huffman@pacebus.com
- ◁ Mr. Joe Voccia, Illinois Dept of Transportation, Telephone 312 793 2111, E-mail vocciajh@nt.dot.state.il.us

6.2 Transit System

6.2.1 Organization

The overall coordination of transit services in the greater Chicago area falls under the Regional Transportation Authority (RTA), which has responsibility for transit policy, service coordination and funding. The RTA Board of Directors consists of representatives of each of the counties in the northeast Illinois area as well as a Chairman appointed by the State Governor. There are three main operating agencies under the RTA, namely Pace Suburban Bus, Metra and Chicago Transit Authority (CTA). Pace operates the commuter bus services in the six county area, Metra operates the commuter rail services and CTA operates both bus services and heavy rail rapid transit services within the central area. Each of these agencies has a Board of Directors, which oversees the affairs of the agency.

6.2.2 Services

Pace provides an extensive network of local and commuter bus services in the greater Chicago area. It also provides a large specialized transit service for people with disabilities

and it provides an extensive vanpool service throughout the Regional area. Bus services connect to commuter rail and rapid transit stations as well as serving major activity centres. Pace has a fleet of about 1000 conventional buses operating from nine operating garages. The Chicago Transit Authority is also involved in the Cermak Road project. CTA is one of the largest transit services in North America, operating a comprehensive bus and rapid transit service. An overview of the two transit systems is provided below.

Suburban Chicago Transit Overview		
	Pace	Chicago Transit Authority
Fleet Size: Buses (All types) Heavy Rail Cars	1000 N/A	2000 1100
Annual Ridership	40 Million trips	440 Million trips
Total Employees	1,350	12,250

TABLE 6.1: SUBURBAN CHICAGO TRANSIT OVERVIEW

6.2.3 Transit Operations

Pace bus operations on the street are controlled primarily by the individual operators operating their buses in accordance with their trip schedule sheet. Schedule adherence is the responsibility of the operator. Pace does not currently have an Automated Vehicle Location (AVL) system but this is currently under investigation. Buses are equipped with radios to enable communication between the bus and the dispatch office at each operating centre. Also, on-street supervision and monitoring is carried out to check on conditions and to assist in dealing with problems.

In the Cermak Road corridor, there are two bus routes operated by Pace and one route operated by CTA. These bus routes connect with the western terminal of a rapid transit line at the boundary of Cicero with the City of Chicago. All three routes operate along Cermak Road, sharing bus stops, to North Riverside and, in the case of Pace, to suburban communities to the west. The combined level of service is about 6 buses per hour in the peak period. The scheduling of the buses is coordinated to ensure even spacing of buses.

6.3 Traffic Control

Cermak Road is a heavily congested arterial road under Illinois DOT jurisdiction. It carries about 30,000 vehicles per day on a five lane (2 lanes in each direction plus turning lane) cross-section. The corridor is 2.5 miles in length with 15 signalized intersections. IDOT is responsible for the installation, operation and maintenance of traffic signals in the corridor. Prior to the implementation of the project, the 15 signals in the corridor were operated as three separate groups. Nine signals at the west end of the study corridor utilized an Econolite closed loop system, with a master controller and individual intersection controllers interconnected. The next five intersections were controlled by a Transyt system, which used time of day programs and did not have an interconnection between the intersections to maintain coordination. The most easterly intersection was part of a signal grouping to the east. The three groups of signals were operated independently.

6.4 Public Transit Priority

6.4.1 Policy

The interest in priority for public transit in the greater Chicago area is related to the amount of suburban growth and the high levels of traffic congestion that is occurring throughout the area. While there was not a specific statement of a policy for transit priority, there are strong concerns with traffic congestion as well as interest in fuel conservation and reduced vehicular emissions. In discussions with representatives of the agencies involved, some of the stated objectives for transit priority were as follows:

- ✧ To encourage greater public transit ridership.
- ✧ To reduce bus emissions related to excess stops and starts.
- ✧ To improve adherence to published schedules.
- ✧ To reduce the number of buses and operating costs.

6.4.2 Background

The Cermak Road project resulted from the establishment of a transit/highways task force in the early 1990's. This group, which involved IDOT, Pace and CTA, was given responsibility to investigate the feasibility of transit priority at traffic signals and to plan a demonstration project. The Cermak Road corridor was selected and a more detailed study conducted to assess the likely effectiveness of transit priority in the corridor and to recommend an appropriate system for implementation. That study investigated and developed detailed recommendations on technology, system design, traffic control strategies and implementation. The study was completed in 1993 and the demonstration corridor became fully operational in 1997.

6.4.3 General Transit Priority Measures

Both Pace and CTA are investigating other transit priority measures and other corridors for transit priority at signalized intersections. However, there does not appear to have been a lot of previous experience with other forms of transit priority.

6.5 Cermak Road Project Description

6.5.1 Description

The Cermak Rd corridor is described earlier in section 6.3. It is a 2.5 mile corridor on a heavily congested arterial road, carrying about 30,000 vehicles per day. There are 15 signalized intersections along the corridor. Transit volumes are relatively light with about 6 buses per hour in each direction during the peak period.

6.5.2 Transit Priority Technology

The existing traffic control system in the corridor required a major upgrade to provide the functions required for the project. As a result, the controllers and cabinets at the 15 intersections in the corridor as well as several additional intersections were replaced with new controllers that were capable of accommodating the desired control logic. These controllers are fully interconnected by fibre optic cable.

Bus detection is provided by a low power radio transmitter mounted on the underside of the bus and conventional detector loops in the pavement. The detector loops are connected to dual-function detector amplifiers in the signal cabinet at each intersection. These amplifiers can detect the bus transmitter separately from general traffic. A loop about 250 feet upstream of the intersection stop bar is used to detect buses entering the transit priority zone and a second loop downstream of the intersection is used to detect clearance of the intersection by the bus. Pace and CTA equipped about 50 buses with the transmitters for use in the corridor. They have installed test stations at their garages to enable bus operators to confirm that their transmitter is operating properly before the bus is taken out on the road.

6.5.3 Control Strategies

The overall strategy for the Cermak Rd project was to provide limited priority to buses using the corridor while ensuring that reasonable signal progression was maintained and side street traffic was not unduly delayed. In the planning studies, two forms of transit priority were identified, as follows:

- * Full preemption, which would be similar to the preemption provided to emergency vehicles. Under this control strategy, detection of a bus approaching would result in provision of a green phase as soon as pedestrian crossings clearances were achieved. This green phase would be maintained until the vehicle cleared the intersection. The normal coordination between adjacent intersections would not be maintained under this form of priority.
- * Partial preemption, which would extend a current green phase or activate a green phase earlier for an approaching bus, within certain limits that would ensure that coordination is maintained between adjacent intersections.

In the case of Cermak Road, the partial preemption form of control strategy is used. This ensures that the overall traffic progression along the corridor is maintained. When a bus is

detected on the upstream detection loop, the controller checks the current status of the signal timing and estimates the arrival time of the bus at the intersection. The arrival time is adjusted to reflect near-side or far-side bus stop arrangements. Then, within adjustable parameters, the controller is able to extend a current green phase to accommodate the bus or to activate the green phase earlier. The parameters used not only ensure basic safety requirements but also ensure that the signal cycle length is maintained to keep the signal progression along the corridor intact.

It should be noted that through the demonstration project, the 15 intersections within the corridor were provided with new controllers that were fully interconnected. The signals were retimed to provide full progression along the corridor and this provided significant improvements for general traffic operations.

6.5.4 Project Issues

The Cermak Road project had three agencies directly involved as participants and a number of other agencies involved as interested stakeholders. This meant that there had to be a significant amount of coordination and consultation in planning the project. Also, there had to be a high level of consensus developed prior to final decisions being made. This is typical of most cities but in the case of Cermak Road the size and complexity of the urban area meant that the inter-agency coordination became even more important.

There were a variety of technical issues discussed in the technical reports. The selection of bus detection technology was given a great deal of consideration. The use of the transmitters and loops used equipment which could be sourced "off the shelf" and which was compatible with the detector arrangement that was in place at many of the intersections. However, the use of dual output detectors was one factor that required the full replacement of the existing intersection controllers. This would likely have been required for other forms of detector equipment as well. The new controllers with the fully interconnected system represented the most significant cost involved but also provided the benefit of significantly improved traffic operations within the corridor.

6.5.5 Evaluation

The installation cost for this demonstration project was reported as \$730,000. This included the new controllers at the 15 corridor intersections and several adjacent intersections, the fibre optic cable interconnect system, some additional detector loops, software development and the bus transmitter equipment. The intersection control equipment was the most significant cost item.

In simulations of the corridor operations with the transit priority system in place, it was estimated that bus travel speeds could be increased by about 24 % over optimized signal timing conditions and about 44% over the conditions before implementation. The running time in the corridor was about 15 minutes before implementation of the system. After the system was operational, the buses services were rescheduled to take advantage of the improved conditions. Actual results to date indicate running times are reduced by 7% to 20%, depending on the time of day. These actual results are related in part to the schedules designed for the routes involved. There may be some potential to further reduce running

time with schedule refinements. Pace reports that they have been able to achieve reduced buses and operating costs as a result of the reduced travel times achieved through this project.

In addition to the reduced running times, the schedule adherence in the corridor has also improved, based on feedback from operators and customers. There has not been any negative feedback from motorists using the corridor or the side streets and the overall satisfaction with the demonstration is quite high.

6.6 Other Developments

The Cermak Road project has served to demonstrate that transit priority can achieve positive results in a congested corridor without excessive disruption of general traffic. Pace is investigating other possible applications of transit priority in cooperation with IDOT and the other agencies. However, no immediate new projects were identified.

6.7 General Assessment

The Cermak Road project is a useful demonstration of transit priority in a heavily congested corridor. The approach to bus detection appears to be cost-effective and reliable. The need to replace the previous traffic control system increased the cost of the project but also provided the benefits of greatly improved traffic operations.

It is also significant that this demonstration project was implemented in a very large urban area with several large agencies involved. While the larger agencies are able to bring greater staff and financial resources to a project such as this, there are greater coordination efforts involved. In the case of Cermak Road, the agencies involved were able to work through these challenges and to implement the system.

7.0 Bremerton, Washington Case Study

7.1 Introduction

Bremerton, Washington is a relatively small community of about 40,000 persons located on the west side of Puget Sound, about a 60 minute ferry ride from Seattle. It is adjacent to a large US naval shipyard, which is also the major economic activity in the community. Bremerton is located within Kitsap County, which has a total population of over 240,000 persons. The community is located on Puget Sound and the road network is constrained by the irregular shoreline and the somewhat rugged terrain away from the shoreline. With the concentration of activity at the Shipyard and at ferry terminals, traffic congestion has been increasing and is a community concern.

The persons contacted regarding Bremerton's experience with transit priority were as follows:

- * Mr. John Clauson, Kitsap Transit, Telephone 360 478 6223, E-mail jclauson@telebyte.com

7.2 Transit System

7.2.1 Organization and Services.

Kitsap Transit is directed by a Board of Commissioners made up of elected representatives of Kitsap County, City of Bremerton and several other communities within the County. The transit system is a Public Transit Benefit Area Authority (PTBAA) that was approved by a local vote to receive 0.3% sales tax funding from the designated benefit area to support the system. In 1993, a local levy was passed, increasing this to 0.5%. Since the early 1980's the system has expanded to become a multi-program system offering a variety of transportation services:

- * Conventional fixed route bus service
- * Paratransit service for frail, elderly and disabled persons
- * Rideshare program with carpool matching services, vanpool and subscription transit services
- * Travel Demand Management advocacy activities

An example of Kitsap Transit involvement in Travel Demand Management is the recent parking plan at the Shipyards where the available parking area is inadequate and the previous pattern of spillover parking on City streets is being curtailed. Kitsap Transit is an active partner in a program to achieve a major shift away from single occupant automobile travel as the main mode of commuting to this major activity centre.

An overview of the Kitsap Transit service is provided in the following table.

Kitsap Transit Overview	
Fleet Size:	
Buses	170
Paratransit vehicles	45
Vans	94
Annual Ridership	5.6 million trips
Total Employees	300
Revenue Service:	
Revenue Kilometres	8,320,000
Revenue Hours	253,370

TABLE 7.1: KITSAP TRANSIT OVERVIEW

Kitsap Transit operates 40 conventional bus routes serving not only Bremerton but also other communities in the County.

7.2.2 Transit Operations Control

Kitsap Transit is fairly typical of smaller transit systems. It operates a number of different routes but many routes have limited hours of service and the frequency of service is typically very low. Bus routes with a service frequency of only 1 or 2 buses per hour is typical. Operations control on the street is primarily the responsibility of the operator, following the trip schedule. There is some level of on-street supervision to assist with problems and to monitor operations. Radio communication is maintained with all vehicles on the road, including supervisor vehicles. There are separate dispatch centres for routed bus service and ACCESS (elderly/disabled service).

7.3 Traffic Control

The City of Bremerton is responsible for the operation and maintenance of the 40 signalized intersections in Bremerton. The City uses Traconex model TMP-390 controllers. Forty percent of the controllers are interconnected with a central monitoring system. In addition, 40 percent of the controllers have a coordination package with signal progression. The Opticom emitters on these signals are manufactured by 3M. The receivers are Model 205 and the discriminators are Model 262.

7.4 Public Transit Priority

7.4.1 Policy

There does not appear to be a specific policy regarding transit priority in Bremerton. However, the information available on transit services in the community clearly indicates that there has been a greater emphasis on public transit in the past 10 to 15 years. When the transit funding support was initially approved in the early 1980's the transit services had deteriorated to a few buses. However, traffic growth in the community and related problems such as parking shortages, ferry terminal congestion and so forth have heightened the importance of public transit services. Kitsap Transit has responded to these challenges by offering more than conventional transit services. The agency has become more of a Travel Demand Management organization, willing to utilize a wide variety of measures to help respond to growing traffic congestion and to influence changes in travel behaviour.

7.4.2 Background

In 1992, the City of Bremerton, Kitsap Transit and the University of Washington began a one year demonstration using the 3M Opticom priority control system. Funding support for the project was provided by the US Department of Transportation. The project was intended as a trial of the technology used as well as an assessment of the impact on both public transit operations and general traffic flow. The system was implemented and an evaluation study was performed by the University of Washington. This study was documented in a report released in 1993. Kitsap Transit has been using Opticom system ever since.

7.5 Traffic Signal Priority For Transit

7.5.1 Description

The Bremerton project involved equipping 43 of the 45 signalized intersections in the City with transit priority. Since the beginning of the project, this has been reduced to 40 signalized intersections in the city, but other intersections throughout the county have been equipped with the Opticom system. Rather than a corridor application, this project can be thought of as an area-wide application with all intersections used by public transit vehicles being equipped with transit priority. This is consistent with the nature of the service with a relatively large number of routes and low frequency of service on each route.

7.5.2 Transit Priority Technology

The Kitsap project used the 3M Opticom Priority Control System which is a system developed and marketed by 3M, primarily for emergency vehicle preemption, but which has also been adapted to public transit priority applications. The system used in Kitsap is referred to as a second priority system because it is able to distinguish and grant priority to emergency vehicles such as fire, ambulance or police vehicles. It appears that this system was

first used in Charlotte, North Carolina for transit priority in the early 1980's although this could not be confirmed as the first application of the Opticom system.

The 3M Opticom system used in Kitsap consists of several components, as follows:

- Each bus is equipped with an optical strobe light transmitter that is activated by the bus operator. This transmitter was mounted on the buses at the front, in the destination sign case. The emitter includes a unique identification code that can be distinguished by the receiver to identify the vehicle type.
- Each intersection has an optical detector, typically pole mounted in the vicinity of the intersection within specified limits to ensure detection of the light transmission.
- The optical detector is connected to a phase selector device within the signal controller cabinet. The phase selector acts as an interface with the signal controller to request priority control.
- A preemption indicator light is mounted near the signal heads to indicate the priority control status of the intersection.

The system in Kitsap is able to distinguish emergency vehicles from buses and to provide priority accordingly. It is used for both transit priority and for preemption by emergency vehicles.

In the reports on this project, it was noted that some effort was required to fine-tune the detection equipment to ensure that bus detection was reliable and did not result in a bus being detected too far in advance of the intersection.

7.5.3 Control Strategies

The Kitsap system is based on "second priority signal preemption" which means that the highest priority is given to emergency vehicles that are detected. In the case of emergency vehicle detection, a green phase is provided to that vehicle as soon as minimum pedestrian clearances are achieved and a red phase can be given to conflicting movements. If the controller is in the process of giving priority to a transit vehicle and a call is received from an emergency vehicle, the emergency vehicle is given immediate priority.

For transit priority, the Bremerton Traffic Department developed a control logic that is used when a bus is detected and an emergency vehicle is not present. On detection, the controller checks the current status of the signals and can then provide an extended green phase up to a specified maximum green or it can initiate an earlier green phase, following pedestrian clearances and provision of a minimum green phase for the cross street. Following bus passage (i.e., detector contact lost with the bus), the controller restores normal signal coordination within 30 seconds. During this recovery, the controller will not accept a new bus detection for at least one cycle.

Activation of transit priority is the responsibility of the bus operator who uses a switch to turn on the emitter at the front of the bus. The Kitsap system has a white preemption indicator light, which can be viewed by the operator. When the controller receives the bus detection signal, the indicator light begins to flash. When the green phase is available to the operator, the indicator light turns to a solid display. At the end of the green phase, or if control has been preempted by an emergency vehicle, the indicator light begins to flash

again. When bus passage is detected, the controller begins to restore normal coordination and the indicator light is turned off.

7.5.4 Project Issues

No particular issue was noted regarding this project.

7.5.5 Evaluation

The cost of the project has not been reported in the project evaluation report. Based on information from 3M a typical cost estimate for this type of system would be about \$4000 Cdn per intersection and about \$2000 Cdn per bus. This would not include controller modifications and programming or other engineering costs. There are indications that the system in Bremerton is also used for fire and other emergency vehicles so the costs would cover more than just the transit application.

An evaluation of bus travel times was conducted on 4 selected routes for runs with the priority system in operation and for runs without the system in operation. To reduce the constraints of the transit schedules, a survey method was used to account for time lost specifically at signalized intersections. The survey found that the average route travel times were reduced by 5% to 16% or by 2.6 minutes to 7.5 minutes. On average, for the four routes, the travel time was reduced by about 4.9 minutes or 10%.

The impact on cross street traffic delay was surveyed at 8 locations. In 4 cases the delay had increased and in 4 locations the delay had decreased and it was concluded that the results were not significant. This may be due in part to the relatively low frequency of bus service and the number of other factors, which could have an impact on side street delay.

As a result of the reduced travel times with the transit priority system, Kitsap Transit was able to reschedule services on most routes. In some cases additional bus stops have been implemented to take advantage of the reduced running time. The transit operators reported that the system generally enabled them to achieve better schedule adherence.

7.6 Other Developments

At the present time, Kitsap Transit is working on having the on-board computers upgraded to be Y2K compliant. Until this is completed, the Integrated Fleet Operations (INFO) system is inoperable and the Opticom system is being operated manually by the drivers. The INFO system tracks buses using the GPS system, comparing where the bus is on the route to where it should be on its schedule, and automatically triggering the Opticom if the bus is behind schedule.

7.7 General Assessment

The Bremerton project is interesting from several points of view:

- It is a smaller transit system without having the advantage of extensive technical resources. To overcome this situation, they used a technology that was largely available off the shelf.
- In Kitsap, the level of bus service on specific routes is low and the routes are spread out. In this case, the form of priority is not focused on a specific corridor but is more of an area application with all signals being equipped.
- The results of the demonstration have been quite positive. Although the improved travel times are not significant enough to permit a savings of vehicles, they have enabled service schedules to be improved with better schedule adherence and the additional flexibility for minor service changes (additional bus stops) within the schedule.

Although not related directly to transit priority, the practice of Kitsap Transit of getting involved in Travel Demand Management activities is interesting and may represent a direction for other smaller transit systems to enhance their value to the community.

8.0 Pierce County, Tacoma, Washington Case Study

8.1 Introduction

Pierce Transit, located in Pierce County Washington, is the second largest transit system in Washington State. Pierce Transit provides public transportation services in the southern Puget Sound area, about 30 miles south of Seattle. Pierce Transit's operations are centered on Tacoma, the largest city in Pierce County and the hub of Pierce Transit's service area. Tacoma has a population of about 190,000 persons and the total population of Pierce County is about 700,000 persons, with the majority of the population being served in the urban areas surrounding Tacoma. Tacoma's economy is based largely on transportation and the lumber industry. Tacoma is a major western railway terminal and is also one of the largest container ports in North America. The geography is dominated by Puget Sound to the west and the Cascade Mountains to the east.

The persons contacted regarding Tacoma's experience with transit priority were as follows:

- Mr. Eric Phillips, Pierce Transit, Telephone 253 581 8080, E-mail ephillips@piercetransit.org
- Mr. Chris Larson, PE, City of Tacoma Engineering, Telephone 253.591.5538, E-mail Clarson@ci.tacoma.wa.us

8.2 Transit System

8.2.1 Organization and Services

The Pierce County Public Transportation Benefit Area (PTBA), also known as Pierce Transit, was formed in 1979 when voters passed a 0.3% sales tax proposal to fund public transportation. The authorization of this taxing authority formed Pierce Transit as a municipal corporation under State legislation. A Board of Commissioners made up of nine elected officials representing Pierce County and several municipalities within the County, including the City of Tacoma, governs the Agency. The Chief Executive Officer is responsible for the management of the system under the direction of the Board.

Pierce Transit provides public transit services to most of Pierce County. The services include: 56 local bus routes, seven days a week, and complementary SHUTTLE demand-responsive paratransit service for persons with disabilities; vanpool and ride matching programs; employer services, including commute trip reduction programs; and, regional express bus service to Seattle, Sea-Tac Airport and Olympia. An overview of the Pierce Transit service is provided below:

Pierce Transit Overview	
Fleet Size:	
Conventional Buses	235
Spec. Transit Vans	85
Vanpool Vans	167
Annual Ridership	13 Million trips
Total Employees	672
Revenue Service:	
Fixed Route	
Revenue Miles (1999)	7,880,312
Revenue Hours (1999)	506,659
Demand Response	
Revenue Miles (1999)	2,979,438
Revenue Hours (1999)	169,841

TABLE 8.1: PIERCE TRANSIT OVERVIEW

Over half of the conventional transit buses are fuelled by compressed natural gas.

8.2.2 Transit Operations Control

Pierce Transit on-street operation of buses is primarily the responsibility of the operator following his printed schedule trip sheet. Service supervision is provided to monitor operations and to assist with operational as well as customer service problems. Pierce Transit SHUTTLE service uses Mobile Data Terminals (MDT's) to assist in scheduling and updating demand responsive services in the field. Transit vehicles and SHUTTLE vehicles maintain radio contact with the operations dispatch office as needed. Supervisors in the field maintain radio and phone communications to support services as needed.

8.3 Traffic Control

The City of Tacoma is responsible for traffic operations on the City streets. Traffic control is provided by a number of closed loop control systems, providing coordination among groups of signalized intersections, generally on the busier routes in the central area. There are also a number of isolated intersections under localized control. The City of Tacoma has 310 traffic signals. NEMA controllers operate 270 intersections. Older mechanical controllers operate 40 intersections. There are 20 closed loop control systems operated by a master controller.

About 230 of the NEMA controllers are included in closed loop systems. About 40 of the NEMA controllers operate independently.

8.4 Public Transit Priority

8.4.1 Policy and Background

In the City of Tacoma increasing traffic congestion has become a public policy issue and improved public transit services as well as Travel Demand Management measures are viewed as key components of a strategy to deal with congestion. The success of the transit priority application in nearby Bremerton also served to increase interest in transit priority in Tacoma.

The following is summarized from the Puget Sound Regional Council's adopted regional plan for ITS. The objectives and related policies are from the 1995 Metropolitan Transportation Plan, the region's long-range transportation plan. These objectives and policies guide the selection of priority ITS projects and programs and provides a regional policy framework that has been adopted by both Pierce Transit and the City of Tacoma.

Objective 1.

Optimize and manage use of the central Puget Sound region's transportation system

Policy: (RT-8.8) Support transportation system management activities, such as ramp metering, signalization improvements, and transit priority treatments, to achieve maximum efficiency of the current system without adding major new infrastructure. Minimize travel time for vehicles, Minimize travel demand for commute trips, Encourage mode shifts to higher occupancy vehicles, and Increase person-carrying capacity of transportation network

Objective 2.

Manage travel demand addressing traffic congestion and environmental objectives, such as reducing energy consumption and emissions

Policy: (RT-8.12) Support transportation system management programs, services, and facility enhancements which improve transit's ability to compete with single-occupant vehicle travel times.

Policy: (RT-8.14) Emphasize transportation investments that provide alternatives to single-occupant vehicle travel to and within urban centers and along corridors connecting centers.

Policy: (RT-8.16) Support opportunities to use advanced transportation and information technologies which demonstration support for regional growth and transportation strategies.

For a complete review of the PSRC regional transportation plan policy, objectives and background visit www.psrc.org.

8.4.2 General Transit Priority Measures

Pierce Transit operations in the City of Tacoma are fully integrated with general traffic. No special traffic operations, street configurations or facilities are provided to give transit an advantage for operations. With the exception of curbside bus zones and pullouts, Pierce Transit operates as any other vehicle in the urban core of Tacoma. For this reason, providing

an advantage for transit through use of signal priority measures offers a long term opportunity to maintain service reliability and on time performance for riders as the areas population and traffic grow.

8.5 Traffic Signal Priority For Transit

8.5.1 Description

The Pierce Transit Signal Priority Project was initially undertaken as a demonstration project in 1996 to determine the feasibility of transit signal priority and to acquire some practical experience that would assist in future applications. A preliminary study was undertaken to determine the most appropriate location for a demonstration and it was determined that S. 19th Street between S. Wilkeson Street and S. Mildred Street was the most appropriate corridor. This corridor, which is heavily congested at several intersections, is located west of the downtown area and is in a more heavily developed part of the City. It is 3.1 miles in length with 11 signalized intersections. There are two bus routes (Route 27 and Route 57) using the corridor and the bus stops were generally nearside. For the demonstration project, a number of the bus stops were moved farside to take better advantage of the transit priority. Service frequencies on the Route #27 and #57 are 15 minutes and 30 minutes respectively. South 19th Street is a busy urban arterial roadway, the majority of which is 5 lanes. Volumes are heavy and intersection congestion is common during all hours.

The demonstration project was implemented in early 1996 and the surveys used for evaluation purposes were conducted before and after implementation.

8.5.2 Transit Priority Technology

The 11 traffic signals in the corridor consisted of three intersections controlled by a Traconex closed loop system operating in a free mode, four intersections controlled by a Traconex closed loop system operating in traffic responsive coordination mode, three intersections controlled by a TCT closed loop system operating in a traffic responsive coordination mode and a single intersection controlled by a Traconex controller operating in free mode. For the demonstration project, this traffic control equipment was utilized and the control groupings were maintained as were previously used. The City of Tacoma did make changes to the control software to provide the transit priority control strategies.

One objective of the demonstration was to gain experience with transit priority technology. Prior to the demonstration four different forms of bus detection equipment were evaluated. It was decided to test two different products, namely Opticom and Loopcomm detectors. Opticom equipment was installed at all 11 intersections and the Loopcomm equipment was installed at 3 intersections that also had Opticom equipment. Opticom equipment consists of an optical emitter that is mounted on the bus, an optical detector that is usually pole mounted near the intersection and a phase selector device that provides the interface with the traffic controller. This was essentially the same equipment that was used in Bremerton with the exception that Tacoma did not use the preempt indicator light component. The Opticom system was able to log ongoing data on the use of the system. This data included

bus identification number, direction of travel, time of detection and length of detection for each occurrence of bus detection. This data was stored in the phase selector in the controller cabinet and was uploaded to a remote computer by telephone connections.

Loopcomm equipment consists of a radio frequency transmitter located on the bottom of the bus and inductance loops in the pavement with a dual detector amplifier to detect the bus separately from general traffic. A loop upstream of the intersection is used to detect the bus approach and a second loop was used at the stop bar to detect bus clearance. The loops used were already in place for traffic control purposes and the locations were not considered ideal. For example, the bus clearance loop would desirably have been at the farside of the intersection to avoid sending a "clearance" signal for a bus waiting at the stop bar for a red light.

Fifteen buses were equipped with the emitters for the demonstration. The evaluation of the demonstration assessed both technologies used.

8.5.3 Control Strategies

The control strategy was based on detecting bus entry and clearance. With the Opticom equipment this was achieved by locating the optical detectors immediately downstream of the intersection and adjusting the sensitivity such that entry detection would occur when the bus was less than 400 feet upstream. Clearance detection would occur when the bus passed out of the detectors range (i.e., downstream). Adjustments were necessary to achieve the desired level of detection accuracy. With the Loopcomm equipment, an entry detector loop and clearance detector loop were used at the intersections. It should also be noted that the Opticom emitter was initially left on all the time to minimize operator distractions but this was later modified to require the operator to activate the optical signal.

Two different traffic control strategies were tested as part of this project. Control strategy A only provided green phase extensions for buses. With this strategy, a bus detection during a green phase would activate a green extension. This would last until bus clearance was detected or the maximum green phase length was reached. The maximum green phase was set to ensure that coordination with the adjacent signals was maintained. For the intersection operating as an isolated signal, a maximum green extension was established in the controller. The control logic ensured that all pedestrian phases were provided and clearance requirements maintained. Also, the logic ensured that no phases were skipped. Control strategy B also allowed the activation of an earlier green phase when the bus was detected on a red phase. This was achieved by shortening the cross street green while still maintaining minimum pedestrian clearances. In this control strategy the green phase was limited, to ensure coordination was not lost. During the demonstration, different maximum green times were tested.

8.5.4 Project Issues

In the reports on the Tacoma project, the issues noted were primarily technical matters, generally as follows:

- * The placement and adjustment of the optical detectors required some fine-tuning. The Opticom emitters were located within the bus destination sign casing and projected

through the glass. The detectors were placed at the farside of the intersection such that they were within 8 degrees horizontal of the bus when at the stop bar. The settings were set to short range detection (i.e., less than 400 feet).

- Initially the Opticom emitters on the buses were installed to transmit continuously. However, it was subsequently found that there were signals in some jurisdictions that also used Opticom for emergency vehicle preemption and the buses were inadvertently activating the preemption. The emitters were modified such that the bus operator had to activate the emitter using a switch.
- Prior to the demonstration, a number of nearside bus stops were relocated to the far side of the intersection to take advantage of the priority system.
- The control logic ensured no changes to pedestrian phases, no skipping of phases and full maintenance of signal coordination. It was felt that further investigation of alternate control strategies that relaxed these constraints might improve the transit operations. However, this was recognized as an area requiring more work.

8.5.5 Evaluation

The cost of the project for the demonstration corridor was reported as \$75,000 for equipment and installation for the 11 intersections and 15 buses.

The evaluation study assessed the impact on bus travel times and found that there was a significant reduction in travel time for one bus route, particularly in the eastbound direction. The savings in different test periods ranged from a 6.0% to an 8.6% reduction in travel time (about 0.6 to 0.9 minutes). Savings were observed in other cases but were not statistically significant. The travel time savings between control strategy A and control strategy B were not significant.

The impact on cross street delay was assessed through manual delay surveys and through detector loop occupancy data. The cross street delay appeared to increase slightly but the differences were not statistically significant.

Bus operators were asked for their subjective assessment of the improvement. About 50% of the operators felt that the system had reduced travel time in the corridor. The evaluation also commented on the equipment used. Both the Opticom and Loopcomm detector systems were reported to provide an acceptable level of detection accuracy and reliability, following the initial adjustments. Loopcomm did not have the ability to record data on the bus priority activities in the same manner as Opticom. It was also reported that further refinement of the control strategies and settings was warranted and may improve the operation.

8.6 Other Developments

Following the 1996 demonstration of Transit Signal Priority (TSP) Pierce Transit was able to obtain grant funding from state and federal sources to implement a full TSP project that would serve low priority transit use, as well as high priority emergency services within the City of Tacoma. While defining the implementation plan, Pierce Transit began an extensive

process of coordination with the affected jurisdictions. The most significant coordination has been with the City of Tacoma, which includes 80 percent of the total project intersections.

Pierce Transit has secured approximately \$2.7 million in grant funding to purchase and install TSP equipment. The project includes modification and installation of signal priority equipment at 110 intersections along some of the most congested transportation corridors in the Pierce Transit service area: 6th Avenue, Bridgeport Way, South 19th, South 56th, South Tacoma Way, Pacific Avenue and parts of Puyallup Ave.

As part of the overall coordination effort to implement the TSP project, agreements with the cities of Tacoma, University Place, Lakewood, and the State DOT will be obtained. Pierce Transit's most significant partner is the City of Tacoma because 83 of the project intersections are within the City. Due to this, significant effort was placed into drafting the interlocal agreement with the City of Tacoma in order to:

- Delineate the specific responsibilities of each agency,
- Specify separate equipment installation and maintenance tasks,
- Establish financial obligations and responsibilities, and
- Establish liability protection for Pierce Transit and the City.

Due to the use of federal and state grant funds in the TSP project, several specific provisions were developed as sections of the interlocal agreement. Specifically the agreement addresses:

- Establishing a per intersection fixed cost for installations which must be performed by City crews.
- Annual certification requirements by the City to assure signal priority operations for the lifecycle of the equipment being provided by Pierce Transit.
- A cost reimbursement process if the City decides to discontinue the project prior to the end date established.
- Inventory and control measures to meet Federal Transit Authority (FTA) requirements.
- Access to data from City owned traffic control equipment.
- A dispute resolution process that reduces the potential for project termination or litigation.
- Agreement to achieve optimal signal timing for transit and traffic.

The agreement developed between the City of Tacoma and Pierce Transit will be used as a template for similar agreements with other participating jurisdictions.

Construction in the City of Tacoma will commence in June, 2000. Initial testing is scheduled to begin in the fall of 2000. Total project construction should be completed by June 2001. Ongoing coordination and testing of signal control strategies is a major component of the agreements. The initial control strategy in the City of Tacoma will accommodate a "green extension" for buses. Additional control strategy development and software testing will be undertaken as a joint project including Pierce Transit and the traffic engineering divisions of participating agencies.

8.7 General Assessment

The Pierce Transit TSP project in Tacoma is a good example of a transit priority project in a smaller city being implemented without extensive engineering work and with a fairly modest budget. The estimated equipment and installation cost to equip 83 intersections in Tacoma is \$750,000.

The results of the 1996 demonstration were not as significant as those that may be achieved in other areas, but this is likely due in part to the nature of the bus service in the corridor and also to the limited capabilities of the control strategies. The demonstration project did demonstrate, however, that transit priority can be achieved with off-the-shelf equipment and without unduly disrupting general traffic. The ongoing experience in Tacoma will be helpful to monitor the performance of the system and of the equipment.

It is also noteworthy that the current Pierce Transit project is a cooperative working effort between Pierce Transit, City of Tacoma Traffic Office, Lakewood, University Place and Washington State DOT staff. A staff committee, including other local agencies not directly involved, was established and enabled the project to proceed in an orderly manner. Ongoing communication and an understanding of conflicting interests in serving the general population from a traffic management standpoint has been emphasized in the current project. A commitment by Pierce Transit to take a very cautious and conservative approach to implementation has allowed jurisdictions with strong concerns to work closely and openly with Pierce Transit.

9.0 Case Study Summary and Conclusions

The five case studies provide an excellent cross-section of the application of transit priority at signalized intersections. They represent very different approaches, in metropolitan areas of several million people to communities of less than 100,000 persons. The case studies were not selected on the basis of the actual results but it is significant that, in all five cases, the transit priority projects have been judged successful on the basis that transit operations have been significantly improved and traffic impact has not been significant. A summary comparison of the case studies is provided below followed by the conclusions of this research.

9.1 Summary Comparisons

9.1.1 General Setting

As noted, the size of the cities selected for the case studies varied tremendously. The actual locations for the transit priority projects also varied. In Toronto, Chicago (Cermak Rd.) and Pierce County (Tacoma) the transit priority projects reported on were located on relatively busy arterial roadways. In Ottawa, a wide variety of project settings were identified, although they were primarily isolated intersections. The selection of priority projects in Ottawa was based primarily on transit and traffic operating conditions. In the case of Kitsap Transit (Bremerton), transit priority was installed at all the intersections within the City used by buses. The volume of buses at the transit projects also varied significantly. Ottawa reported bus volumes as high as 100 buses per hour. The Toronto Queen St streetcar project had streetcar volumes of over 15 vehicles per hour and the Brimley Rd bus project had bus volumes of 12 buses per hour in the peak period. The other projects reported volumes of 6 or less buses per hour during peak periods.

9.1.2 Reasons for Transit Priority

In the five case studies, the general reasons for developing and implementing transit priority projects appear to differ somewhat. In Ottawa, there appears to be a very strong policy commitment to increasing public transit use and taking various steps to achieve this travel behavioral change over a 20 year period. Transit priority is clearly identified in transportation plans as one measure to be used to encourage greater transit use. In Bremerton and Tacoma, there appears to be a policy commitment towards both transit and travel demand management as a means of limiting the undesirable affects of automobile congestion. In Toronto and Chicago, the interest appears to be more in improving the efficiency of transit operations as a cost containment measure. It is noted that in the evaluation in all 5 case studies, the emphasis was on determining the improvements to bus travel time and additional delay to general vehicular traffic.

It is also noted that the projects reviewed for Toronto, Chicago and Tacoma were all implemented as demonstration projects, whereas, the projects in Ottawa and Bremerton were seen as a full commitment to transit priority measures.

9.1.3 General Approach

In all five case studies the transit priority projects have been implemented through a working partnership between transit and traffic staff. In 4 of the 5 cases, the project appears to have started with a joint study to assess feasibility, appropriate location, technology and so forth. In the Ottawa case, a joint working group has been formed to coordinate the work but traffic staff have responsibility for design and implementation and transit staff have responsibility for identifying problems and providing feedback. This appears to have worked well in that a substantial number of priority measures have been implemented in a relatively short period. The progress in Ottawa is related in a large part to the strong commitment of the traffic staff to the implementation of transit priority measures.

In Toronto, Chicago and Tacoma, it was decided to start with a demonstration project to test the technology, operating strategies and results. This has worked particularly well in Toronto where the demonstration projects have provided the basis to significantly expand transit priority for streetcars and to a lesser extent for buses. In Chicago and Tacoma, it appears that further transit priority measures will follow the initial demonstration projects but the progress isn't as clear at this time. In Bremerton, the initial experience has provided encouragement to proceed with a more advanced system with a link to an on-board Automatic Vehicle Location system and this is apparently underway. In the Ottawa case, the policy commitment was very strong and the program is viewed as an ongoing program.

9.1.4 Traffic Control Technology

The detection of buses to provide signal priority presented a challenge in all the case studies. Toronto used radio frequency transponders and loops for the Queen St project and infrared transmitters with receivers for the Brimley Rd project. Ottawa has used conventional inductance loops to date (single loops in bus lanes and double loops in mixed traffic lanes to check for longer vehicles) but recognizes that further projects will require a more reliable and adaptable detection technology. The Cermak Rd. project in suburban Chicago used radio frequency transponders and detector loops. Both Bremerton and Tacoma used the 3M Opticom light transmitter system and Tacoma also used the Loopcomm (transponders and loops) system at three intersections. In 4 cases, both upstream approach detection and downstream clearance detection was employed although the Opticom system relies on the bus passing through the detection zone to indicate clearance. In Ottawa, the specific projects generally used only bus approach detection to activate the particular transit priority strategy. This is related in a large part to relying on inductance loops and the nature of the approach lane configuration for bus detection. Ottawa is currently investigating other forms of bus detection to enable more refined control strategies. With bus detection technologies, other than the normal inductance loop detectors, an interface device is also required at the traffic controller to initiate the local control algorithm.

9.1.5 Traffic Control Strategies

In all the case study projects, the control strategies for providing bus priority consist mainly of extending a current green phase or shortening a side-street green phase to facilitate bus passage of the intersection. Ottawa has used some other control measures in specific cases and Toronto is investigating more advanced control strategies. It is interesting that Tacoma tested green extension only and green extension plus red truncation strategies and didn't find a significant difference. In all cases, the particular traffic control strategies had certain limits on phase extensions incorporated into the algorithms. In the Cermak Rd and Tacoma, the control logic does not appear to allow the normal signal cycle length to be changed whereas in Toronto and Bremerton, the cycle length apparently could be changed to give greater priority and was restored later by the traffic control system. While the case studies, particularly in Toronto and Chicago, invested considerable effort in the traffic control strategies and controller algorithms, this still appears to be an area for further research.

None of the case studies investigated currently utilize an Automated Vehicle Location (AVL) system to enhance transit priority strategies. This has been done in several European projects and during this study it was learned that there is a transit priority project in Montgomery County, Maryland and another under development by the Chicago Transit Authority that apparently integrate an AVL system with transit priority at signals. The advantage of this type of integrated system is that buses running behind schedule can be identified and given a higher level of priority. The Kitsap Transit system in Bremerton is currently investigating this enhancement for their transit priority project. This will be an area of future research and development in North American transit systems.

9.1.6 Evaluation

The Table 9.1 provides an overview of the evaluation of the case study transit priority projects:

In comparing projects, the cost of the Cermak Rd project in Chicago appears quite high. In this case, the traffic control system was almost entirely replaced and significant improvements in overall traffic conditions were achieved as a result. It is also noted that the costs in Toronto represented a considerable research and development effort and are likely to be significantly reduced as further installations take place.

In all cases, the transit priority measures have achieved significant savings in bus travel times. In the case of Toronto, further expansions of the transit priority measures have enabled significant savings in transit vehicles with a corresponding savings in operating costs. Both Kitsap Transit and Pace bus reported that the improved travel times enabled service schedules to be improved.

Project Location	Implementation Costs	Transit Impacts	Traffic Impacts
Toronto Queen St	\$217,000 (6 intersections) (Cdn)	Reduced travel time 22 to 77 seconds. Reduced travel time variation 18 to 73%	Minor variations, not significant.
Brimley Rd	\$355,000 (10 intersections) (Cdn)	Reduced travel time 34 to 84 seconds.	Improved main street travel but some minor side street delay increase.
Ottawa	Varies.	Generally positive.	No significant problems reported.
Chicago	\$730,000 (15 intersections) (US)	Reduced bus running time by 7 to 20%. Reduced numbers of buses reported.	Significant improvement thru new controllers and signal timing.
Bremerton	Not reported.	Reduced bus travel time by 5 to 16%. Able to reschedule service and add bus stops.	No significant side street delay reported.
Tacoma	\$75,000 (11 intersections) (US)	Reduced bus travel time by 6 to 9%.	No significant side street delay reported.

TABLE 9.1: CASE STUDY EVALUATION OVERVIEW

The case studies also were concerned with undesirable impacts on vehicular traffic. In all cases the general mixed traffic impacts were not significant. In fact, the transit priority improved the main street traffic operations and any increases in side street delay were not significant. This perhaps indicates that there is potential for greater transit improvements as experience is gained with traffic control algorithms.

Another objective with transit priority is to improve customer service and thereby increase transit ridership. None of the case studies were able to report any impact on transit ridership and this is likely due to the fact that the specific signal priority project results are not likely to be perceived readily by customers. Also, these projects are generally fairly limited and have not been in place a long period of time. Other measures, such as some of the measures outlined in Chapter 2.0, are probably more visible to riders and general public and may be perceived by transit customers more positively.

9.2 Conclusions

Overall, the case studies have indicated very positive results with transit priority at signalized intersections. The transit systems involved have expanded or plan to expand the use of transit priority at signalized intersections, based on their initial experience. The primary benefits appear to be reduced running time for transit vehicles and improved schedule adherence. This has resulted in reduced operating costs in some systems. In conjunction with other transit service improvements, transit priority may also lead to increased ridership over a longer period of time.

It is significant that the case studies were all able to achieve improved transit vehicle operating conditions without significant negative impacts on mixed traffic. This should not be interpreted that this will always be the case. Rather, it indicates that a well designed transit priority project can be implemented and provide transit operating improvements in specific situations without negative traffic impacts. It is significant that in the two large metropolitan cities (i.e., Toronto, Chicago) a considerable effort was required to plan, design and implement the transit priority projects.

It is also significant that two of the case studies were in relatively smaller cities (i.e., Bremerton, Tacoma) and were able to use off-the-shelf technology to implement a successful project. This serves as an indication that transit priority at signalized intersections doesn't have to be limited to large cities and doesn't necessarily require significant new technology.

Finally, it is noted that the case study in Ottawa probably has been active for the shortest period of time but that a significant number of measures have been implemented. This appears to be a result of a strong policy commitment to transit priority combined with an ongoing development group within the traffic section.

10.0 Planning and Implementation Considerations

Based on the research conducted through this project, including the many contacts with staff involved with transit priority planning and implementation, there are a number of considerations which should be recognized by transit managers and other professionals in the planning and implementation of transit priority projects. These are discussed briefly below.

10.1 Policy Direction

The findings of this study indicate that transit priority is clearly a cost-effective strategy to improve public transit service and efficiency. When implemented on a large-scale basis, it can enable a significantly higher level of transit capacity and service to be achieved using bus operations. The implementation of transit priority in a city, however, is unlikely to occur on a significant scale without a clear policy direction from the City Council or the equivalent elected body. Ottawa is an excellent example of a strong policy direction. In that case, Regional Council committed to a transportation plan that involved greater utilization of public transit services. Recognizing that this would require a change in travel behavior, a specific policy of transit priority was adopted. The Region's Official Plan included the following specific policy statements:

- 10. Incrementally implement the transit priority network on Regional roads, as shown in Schedule E, Transit Network.*
- 13. Implement elsewhere, transit priority measures, such as traffic signal priority and bus lanes, where required to maintain a reliable and competitive transit service.*
- 14. Undertake public awareness programs on transit priority measures to promote understanding and acceptance of their value.*

These policy directions, along with other commitments to a strong public transit service, provided the necessary direction to the staff organization in Ottawa to proceed with a program of transit priority measures. The experience with transit priority in European cities is another example of where strong policy commitments to public transit, and even automobile restraint in some instances, has enabled large scale transit priority programs to be developed and operated successfully.

Without a strong policy commitment from Council, planning and implementation is dependent on the efforts of staff that are often in separate departments of the organization. This creates jurisdictional difficulties since priorities in separate traffic and transit organizations are likely to be different. In these cases the planning and implementation of projects can be very time consuming and the outcomes are uncertain.

10.2 Project Approach

The approach taken to develop a transit priority program should reflect the level of policy support and direction from elected representatives. It would appear that there are at least two possible approaches.

Where there has been a strong policy directive to improve the role of public transit in accommodating the community's travel needs, the approach followed in Ottawa and Bremerton (Kitsap County) may be the preferred strategy. In these two cases, the transit and traffic staff organized and proceeded with a fairly large-scale implementation of transit priority measures. They still endeavored to make sure that the measures would be cost-effective. That is, they developed measures that responded to transit operating problems but did not create undue traffic disruption.

The other case is where the policy direction is not as clear or the working relationships within the staff organizations are not as strong. In these instances, the development of transit priority on an incremental basis is likely to be the more successful approach in the long run. This could involve demonstration projects, for example. By working on an incremental program, the opportunities to demonstrate the results of transit priority can be used to develop greater community support and the necessary working relationship between transit and traffic staff can be developed.

10.3 Project Organization

In all the case studies, the planning, design and implementation of transit priority involved a joint working effort by traffic and transit staff. While the transit staff understand the problems caused by traffic congestion and the benefits realized through reduced bus travel time, the knowledge and experience of traffic engineering staff is necessary to design projects that operate effectively and achieve the desired results. Particularly, with transit priority at signalized intersections, the involvement of traffic staff is essential to the project. An important early step to developing a transit priority program will be the development of a cooperative working group involving both transit and traffic staff. A strong mandate to such a group is important as well as an understanding of the respective roles of the members. From the case studies it is clear that these projects require a considerable allocation of staff resources to carry out the necessary work. It is also clear that transit priority projects take time to plan and implement. Project organization is a key step in the process.

10.4 Public Awareness

In this report a wide variety of transit priority measures have been identified and there are others that may also be effective in specific situations. It is necessary that the measures in a particular community are understood and accepted by the general public. The provision of public information is an important ingredient in the development of successful transit priority projects.

Transit priority at signalized intersections may not be as readily noticed by the general public as other priority measures but good public information on the project and the results is still helpful for long term community support. In the case of transit priority measures that are more visible, such as bus lanes, it is very important that the public can see that they are being utilized. Motorists are likely willing to tolerate some additional delay if it appears that a significant number of people are benefiting as a result. However, if there is no apparent

reason for the delay, a public backlash may result. Two key considerations are suggested in the planning phase of a transit priority program:

- The program should include public information.
- Priority measures that are readily visible to the public should be seen to be well utilized.

Recognizing public concerns, some agencies have broadened the use of transit priority measures to include HOV's, bicycles or other vehicle types. This should be carefully considered in each particular case. If the inclusion of other vehicles reduces the effectiveness of the facility, then the initial reasons for transit priority may be defeated. On the other hand it may be a strategy to make a project more useful and acceptable.

10.5 Project Justification

In the case studies, it was suggested that there are different reasons or justification for transit priority. Notwithstanding the particular reasons that a transit priority project is being considered, it is important for transit managers to have a sound understanding of their own operations and to be well prepared in the planning stages. This should include: reliable data on operating conditions, preferably including not only bus running time but also bus time spent waiting at signals and time spent in traffic queues. The level of schedule deviation from trip to trip is also important in considering the potential benefits of transit priority.

The schedule and running time conditions on the route should be reviewed carefully. Where there is already some excess recovery time available in the schedule, transit priority may enable service levels to be maintained with a reduced number of vehicles. In some situations, the operating cost savings may provide the necessary justification to support a transit priority project. In any event, it is suggested that transit managers interested in a transit priority project should develop a sound understanding of their operations and the potential benefits and that this should be supported with reliable data and estimates.

10.6 Technology Selection

Active transit priority at signals requires technology for bus detection and for implementation of modified traffic signal timing to provide the desired priority. In the 5 cases investigated in this study, a number of different approaches to bus detection technology were used:

- Customized detection technology was developed in some cases to provide the desired level of performance.
- Off-the-shelf systems are available and were shown to operate satisfactorily in some systems.
- Conventional traffic detection loops were used in specific situations, albeit with some limitations.

The selection of the most appropriate technology will require investigation in each city, based on the objectives and specific strategies being pursued. The more specialized bus detection equipment enables a higher level of detection accuracy and will provide improved transit operations with less impact on general traffic. There are certainly a variety of options

available, including off-the-shelf equipment. A likely future development in North America is the use of transit AVL systems for bus detection. This should provide more sophisticated control strategies that would improve the transit priority performance by enabling selective priority based on bus schedule status. Experience in Europe has shown these systems to be effective in providing transit priority at signalized intersections.

In addition to the bus detection components, an interface is required with the traffic controller to initiate a new timing plan when buses are detected. In the case studies, specific components were selected or designed. Also, modifications to the traffic controller logic are required to enable new timing plans. In the case studies, the traffic agencies involved developed and tested algorithms to accommodate the desired transit priority strategy and implemented these in the controllers. In some cases the traffic control logic was tested extensively through simulations of the operation. Particularly, in corridors with coordinated signals, a considerable effort is required to develop suitable control logic.

10.7 Transit Priority Opportunities

In cities considering investment in new or replacement technology for traffic control systems or transit AVL systems, the future opportunities for inclusion of transit priority should be recognized. For example, cities may be enhancing their traffic control system to provide first order preemption at traffic signals for emergency vehicle priority. In these situations, the option of also providing second order bus priority at the signalized intersections should be also considered because the additional cost may not be great. Transit managers should discuss this particular option with their peers in the traffic group because the economies of scale may make this particular enhancement attractive.

Transit systems considering the implementation or upgrading of an AVL system should consider possible inclusion of bus detection and tracking functions for transit priority purposes. The feasibility of including this provision will likely be different in each case. However, it is a point at which the opportunity should be investigated. Similarly, if a municipality is upgrading or implementing a new traffic control system or controllers, this is an appropriate time to review the possibility of providing transit priority capabilities and making provision to add them to the system in the future. However, identification of such opportunities will only be possible if there is a pre-existing dialogue and cooperative relationship between transit and traffic staff. This needs to be the first step in seeking to provide priority to transit vehicles in the traffic system.

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10. Traffic and Highway Engineering, Nicholas J. Garber and Lester A. Hoel, West Publishing Co., 1988.
11. Canadian Capacity Guide for Signalized Intersections, Second Edition, Institute of Transportation Engineers District 7 Canada, 1995.
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13. Geometric Design Standards for Ontario Highways, Ontario Ministry of Transportation, Ronen Publishing House, 1985

Appendix A

LITERATURE REVIEW NOTES

CANADIAN URBAN TRANSIT ASSOCIATION

STRP Project 99-2 "A Primer on the Design and Implementation of Transit Priority at Signalized Intersections for the Benefit of Transit Managers"

LITERATURE REVIEW NOTES

1. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Adaptive Control of Transit Operations

Author: Guey-Shii Lin, Ping Liang, Paul Schonfeld, and Robert Larson

Agency: University of Maryland

Publisher: Project MD-26-7002 Federal Transit Administration

Date: November 1995

GENERAL REVIEW NOTES

Adaptive signal control considers transit operational factors and traffic control factors in real time. Two simulation models considered in this paper, Bus Dispatching Control and Signal Control Model. Dispatching Control measures transit system performance. Signal Control measures vehicle delay, stops, etc. Findings are that headway-based control minimizes wait time, schedule-based control minimizes total cost. Signal control model indicates bus priority is effective for short headway situations. Network tests show reduction in average bus delay of up to 55% and with 5-minute headway, combined costs reduced 6% with priority control.

DESCRIPTION OF PROJECT

Type of Strategy: Simulation of a variety of priority strategies in a signalized network

Location: Theoretical models

Transit Agency: N.A.

Issues Noted: Discusses types of control strategies

Results Reported: Theoretical results

OVERALL ASSESSMENT

Good theoretical discussion. Also good discussion about both transit priority strategies and signal control strategies.

2. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Control Strategies for Transit Priority

Author: Alexander Skabardonis

Agency: Institute of Transportation Studies, Univ of Calif., Berkeley

Publisher: UCB-ITS-PRR-98-2

Date: January 1998

GENERAL REVIEW NOTES

Study on transit priority strategies in a signalized corridor. Strategies included passive priority settings such as street designs and transit weighted signal settings. Active strategies are forms

of signal preemption that are more applicable to isolated intersections. Strategies in this study focused on transit improvements with minimal adverse impacts on traffic. Application tested on a 21 signal major arterial corridor in the East Bay area. Strategies tested showed improvements to bus delay with insignificant impacts to general traffic. Good discussion of both transit priority and traffic control strategies along with current technology. Also, lots of references.

DESCRIPTION OF PROJECT

Type of Strategy: Model analysis (Transyt-7F & TRAF-NETSIM) on several passive strategies, including alternate bus stops, transit weighted signal timing plans. Active strategy included bus preemption at selected signals.

Location: San Pablo Ave in East Bay area

Transit Agency: Not stated – (AC Transit?)

Issues Noted: None – appears to be modeling analysis only.

Results Reported: Estimated improvements to bus delay and travel time. Insignificant impact on general traffic.

OVERALL ASSESSMENT

Good research paper with considerable information on current traffic practice. Good examples, lots of references and useful results. However, this is primarily a research report based on modeling analysis.

3. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Bus Priority in SCOOT

Author: G T Bowen

Agency: Driver Information Traffic Management Division, DOT

Publisher: Transportation Research laboratory

Date: 1997

GENERAL REVIEW NOTES

Paper discusses development of SCOOT to include bus priority. Discusses different strategies for bus priority in signalized networks based on local or central green-time extensions and green phase recall. Good discussion of SCOOT and priority logic.

Bus detection by transponder on bus (London) or AVL system (Southampton). Mentions other methods.

Simulations conducted and showed reduction in bus delay, particularly in lighter traffic with both extensions and recalls. However, recalls were also disruptive to car traffic.

Implementation described in London and Southampton. Results reported for Camden Town in London. Achieved average bus delay savings of 5 seconds per intersection (22%) using local controller extensions and central recalls. Other traffic not impacted by local extensions but incurred delays with recalls.

DESCRIPTION OF PROJECT

Type of Strategy: Bus priority at intersections using SCOOT and both transponder and AVL detection.

Location: London and Southampton, U.K.

Transit Agency: N.A.

Issues Noted: Delays to general car traffic due to bus priority (with green phase recall strategy)

Results Reported: Reduced bus delay with green extension strategy and recall strategy. Car traffic delay with recall strategy.

OVERALL ASSESSMENT

Excellent discussion of bus priority in a SCOOT-controlled signalized network.

4. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Canadian Capacity Guide for Signalized Intersections – Second Edition

Author: S Teply, D Allingham, D Richardson, and B Stephenson

Agency: Institute of Transportation Engineers District 7 (CITE)

Publisher: ITE

Date: June 1995

GENERAL REVIEW NOTES

This is a basic guide for signalized intersections with emphasis on Canadian conditions. Sections include Analysis (traffic flow, saturation flow, timing, pedestrians/bicycles/transit, traffic responsive operation), Planning & Design (signal timing, etc), Evaluation (evaluation criteria, capacity, queuing, other), Surveys and Basic Example. Transit provisions are noted in methods.

DESCRIPTION OF PROJECT

Type of Strategy: N.A.

Location: N.A.

Transit Agency: N.A.

Issues Noted: N.A.

Results Reported: N.A.

OVERALL ASSESSMENT

This is a manual that is used by many traffic engineers in Canada. It is a standard reference, along with the Highway Capacity Manual.

5. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Bus Priority Systems

Author: NATO Committee on the Challenges of Modern Society

Agency: NATO

Publisher: Transport and Road Research Laboratory (TRRL)

Date: 1976

GENERAL REVIEW NOTES

A general overview of a wide variety of transit priority measures, including with-flow bus lanes, contra-flow bus lanes, freeway priority, priority access to freeways, bus-only streets, busways, priority at traffic signals, other, comprehensive schemes. Also a number of actual examples.

Chapter on signalized intersections discusses strategies such as adjusting cycle time, phase splitting, area schemes using BUS TRANSYT, bus actuated signals (with transmitters), gating (restrict one or more movements).

Examples from Glasgow (BUS TRANSYT), Paris (bus-actuated), Southampton UK (gating). Actual results from these projects are all positive.

DESCRIPTION OF PROJECT

Type of Strategy: A wide variety of priority strategies. Signal timing (Glasgow), Signal preemption (Paris), traffic gating (Southampton)

Location: UK & Europe for signal priority

Transit Agency: N.A.

Issues Noted: Increased travel time to other traffic

Results Reported: Improvements to bus travel time and delays in each example.

OVERALL ASSESSMENT

Good overview of the range of transit priority measures. Discussion of signalized intersections useful but dated.

6. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Automatic Vehicle Location/Control and Traffic Signal Preemption – Lessons from Europe

Author: Chicago Transit Authority

Agency: Federal Transit Administration

Publisher: Chicago Transit Authority

Date: September 1992

GENERAL REVIEW NOTES

This is a trip report combined with various papers and material collected on a trip to Europe. Contents include:

Chap. 1 Info on traffic signal preempts, hardware and operations.

Chap. 2 AVL/Control systems.

Chap 3 Control Centres (1 page)

Chap 4 Info signs (2 pages)

Chap 5 City Reports – Osnabruck (AVLC, signal priority at 13 intersections, bus only street). Cologne (control centre). Wiesbaden (AVLC, signal priority mentioned briefly, passenger counting). Saarbrücken (AVLC, plans for signal priority, smart cards). Stuttgart (AVLC, signal priority for rail only). Zurich (AVLC, extensive signal priority). Hannover (AVLC, extensive signal priority). Amsterdam (extensive signal priority, AVLC). Paris (extensive AVLC, control centre).

Papers attached to report include the following:

-The BON Standardized Management System (Wiesbaden). AVLC system with signal interface.

-SSB Control Centre (Stuttgart)

-Green on Request (Stuttgart) Describes priority system being implemented, incl h/w, operations.

-Taxi Service (Stuttgart)

-Several papers from Zurich with some info on signal priority system.

-Hannover papers on AVLC and LRT.

-Papers from Amsterdam on traffic control (incl transit priority)

-Paris paper on AVLC system

DESCRIPTION OF PROJECT

Type of Strategy: various but generally signal priority within a network

Location: various

Transit Agency: various

Issues Noted: no major issues noted

Results Reported: varies but some results noted.

OVERALL ASSESSMENT

Good general overview of early 1990's developments in continental Europe. Amount of detail varies.

7. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Transit Priority - Programs that Put People First

Author: TransVision Consultants Ltd (Tom Geehan)

Agency: Crown Corporations Secretariat and B C Transit

Publisher: N.A.

Date: October 1994

GENERAL REVIEW NOTES

This is a comprehensive planning study for transit priority program in Greater Vancouver. Report includes overview of transit priority measures; description of current transit priority measures in Vancouver, including about 9 bus-actuated signals; discussion of challenges; identification of opportunities; evaluation of different proposals and conclusions.

DESCRIPTION OF PROJECT

Type of Strategy: Plan for various transit priority measures

Location: Greater Vancouver

Transit Agency: BC Transit

Issues Noted: General discussion of challenges.

Results Reported: General comments on current projects and cost/benefit estimates of proposed projects.

OVERALL ASSESSMENT

Some general information on transit priority but not much on priority at signalized intersections.

8. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Transit Priority Study 1990 Final Report

Author: Toronto Transit Commission, Metro Toronto, City of Toronto

Agency: TTC/Metro/City

Publisher: N.A.

Date: December 1990

GENERAL REVIEW NOTES

Joint study conducted to assess transit priority for a number of locations within Toronto. Six heavily used streets were selected (Bathurst, Dufferin, Eglinton West, King, Ossington and Wilson) and investigated in detail. Considered a variety of measures (bus lanes, parking, turn restrictions, fixed signal timings, Queue jump lanes) and developed recommendations for each location. Report includes an implementation schedule.

DESCRIPTION OF PROJECT

Type of Strategy: Variety of measures proposed, including signal timing changes.

Location: six corridors

Transit Agency: TTC

Issues Noted: traffic issues

Results Reported: N.A.

OVERALL ASSESSMENT

Deals with general priority measures. Very little on signal priority.

9. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Main Line Traffic Signal Priority Study Phase IV Final Report

Author: Metro Toronto Roads & Traffic, TTC, MOH and City of Toronto

Agency: see above

Publisher: N.A.

Date: April 1989

GENERAL REVIEW NOTES

Planning study of priority at signalized intersections along Queen St for Streetcars. Five signal preemption strategies evaluated. Concluded a demonstration project should be undertaken for a six intersection segment, using active transponders on streetcars. The strategy would utilize central control and limited preemption/coordination.

DESCRIPTION OF PROJECT

Type of Strategy: Transit priority thru signalized area.

Location: Queen St West in Toronto

Transit Agency: TTC

Issues Noted: Costs, traffic impacts

Results Reported: N.A.

OVERALL ASSESSMENT

Planning document but signal priority strategy is directly relevant.

10. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Mainline Traffic Signal Priority Study Phase V- Demonstration Project Final Report

Author: Cansult Engineering Ltd.

Agency: Metro Toronto Transportation Dept and Toronto Transit Commission

Publisher: N.A.

Date: April 1991

GENERAL REVIEW NOTES

This project included installation of priority for streetcars on Queen St W and subsequent evaluation of actual results.

Considerable detail is provided in the report. Six intersections along Queen St involved. Transponders on the streetcars were used with two loops at each intersection (request loop, cancel loop). Intersection controllers receive preempt calls. Control algorithm developed thru a simulation analysis and it provided windows for extension of mainline green or truncation of side-street green. Travel time savings for streetcars of up to 20% in PM and 6% in AM observed. Implementation costs and hardware issues discussed in detail.

DESCRIPTION OF PROJECT

Type of Strategy: Streetcar priority through series of signalized intersections.

Location: Queen St West

Transit Agency: TTC

Issues Noted: Report discusses variety of detailed implementation issues (mostly technical)

Results Reported: Significant travel time savings measured.

OVERALL ASSESSMENT

Excellent example of signal priority with extensive discussion of technical issues.

11. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Mainline Traffic Signal Priority Study – Phase VI – Bus Priority Demonstration

Author: Metro Toronto Transportation and TTC

Agency: Metro Toronto Transportation, Toronto Transit Commission, Ministry of Transportation

Publisher: Metro & TTC

Date: December 1997

GENERAL REVIEW NOTES

Generally deals with a demonstration project for ten signals on Brimley Rd in Metro Toronto. Detailed descriptions of the corridor, traffic algorithm used, evaluation method and results, benefit/cost analysis.

DESCRIPTION OF PROJECT

Type of Strategy: Transit signal priority for buses thru corridor.

Location: Brimley Road, Toronto

Transit Agency: TTC

Issues Noted: Technical issues related to hardware, traffic algorithms, evaluation. Also some disagreement between transit and traffic on interpretation of results.

Results Reported: Reductions of transit travel time and delay. Also some reduction for general traffic. Benefit/cost analysis was positive.

OVERALL ASSESSMENT

Excellent discussion of transit signal priority with considerable detail.

12. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Review of Bus Priority Measures

Author: MM Dillon Ltd (Chris Bishop)

Agency: City of Winnipeg

Publisher: N.A.

Date: March 1987

GENERAL REVIEW NOTES

Report reviews the transit operating conditions in the central area and discusses the potential application of a wide range of measures. Signal priority is assessed using TRANSYT 7F. The proposals are evaluated and an implementation plan is outlined.

DESCRIPTION OF PROJECT

Type of Strategy: Overall plan for Transit Priority in Downtown Winnipeg, using bus lanes, bus-only street, signal priority, yield policy, queue jumper lanes, bus only signals.

Location: Downtown Winnipeg

Transit Agency: City of Winnipeg Transit

Issues Noted: various technical issues

Results Reported: Planning study with estimated results.

OVERALL ASSESSMENT

General planning study. Not a lot of detail on signal priority.

13. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Transit Priority – Getting the Most out of Your Investment

Author: OC Transpo and Region of Ottawa-Carlton

Agency: OC Transpo/RMOC

Publisher: N.A.

Date: October 1999

GENERAL REVIEW NOTES

Examples of a variety of transit priority measures, with reference to Ottawa

OVERALL ASSESSMENT

Good overview of example priority measures but little detail.

14. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Signal Priority in Suburban Chicago

Author: Bob Huffman, John Paquet, Joseph Weesner, Mark Pitstick

Agency: Pace Suburban Bus Service, Civiltech Eng., Illinois DOT

Publisher: ??

Date: ??

GENERAL REVIEW NOTES

Short paper on a demonstration project on Cermak Rd in suburbs of Chicago. 2.5 mile corridor. Used a transponder system, loops upstream of intersection, fiber optic interconnect cable and replacement controllers at 15 intersections. Installed in 1996. Provides data on operations improvements afterwards.

DESCRIPTION OF PROJECT

Type of Strategy: Signal priority for transit in a major corridor.

Location: suburban Chicago

Transit Agency: Pace suburban bus service

Issues Noted: none reported

Results Reported: Transit operating improvements, increased customer satisfaction.

OVERALL ASSESSMENT

Appears to be a very good example of transit priority thru signalized corridor. Paper is a fairly brief.

15. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Traffic Signal Priority Treatment for Transit Fleets: Myth vs. Reality

Author: Kim Christopher & Dave Bruggeman

Agency: 3M

Publisher: ?

Date: ? 1990's

GENERAL REVIEW NOTES

Information about 3M Opticom and INFO systems. Provides description of these. Also refers to transit priority projects in Bremerton (Kitsap), Pierce Transit in Tacoma WA, Phoenix Rte 52. Provides some general detail on these projects.

OVERALL ASSESSMENT

Information on 3M Opticom system. Otherwise very general.

16. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: ITS Technology Solving Bus Transit Priority Needs – The Better Way Gets Better

Author: John Greenough & Richard Noehammer

Agency: City of Toronto and TTC

Publisher: ITS World Congress 1999

Date: 1999

GENERAL REVIEW NOTES

An overview of the Transit Priority projects in Toronto.

OVERALL ASSESSMENT

Good general summary.

17. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Smooth Integration of Public Transport in Urban Control Networks

Author: Siebe Turksma

Agency: Peek Traffic BV

Publisher: ITS World Congress 1999

Date: 1999

GENERAL REVIEW NOTES

A general description of transit priority, generally in Europe, and the focus is mainly on current technology.

18. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: A Transit Signal Priority Impact Assessment Methodology – Greater Reliance on Simulation

Author: J Dale, R Atherley, T Bauer, and L Madsen

Agency: Innovative Transportation Concepts & King County DOT (WA)

Publisher: TRB

Date: January 1999

GENERAL REVIEW NOTES

Discussion of transit priority evaluation, including simulation. Primarily deals with the evaluation process.

19. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Priority for Buses Serving Central Zones

Author: Gerhard Heunemann et al.

Agency: Stadtwerke Wiesbaden

Publisher: UITP Sydney Congress

Date: 1993

GENERAL REVIEW NOTES

40 page discussion paper on bus priority with good detailed examples. Lots of general information, not much on specific projects.

OVERALL ASSESSMENT

Very good overview of the state of the art, primarily European.

20. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Pierce Transit's Signal Priority Demonstration and Implementation

Author: Bradley Funkhouser

Agency: Pierce Transit, Tacoma WA

Publisher: ?

Date: ?

GENERAL REVIEW NOTES

Description of Transit signal priority demonstration project on an 11 intersection corridor in Tacoma, involving 15 buses. Demo took place in 1996. Note that some bus stops were moved far-side. Two control strategies were tested. Travel time results provided for each strategy.

DESCRIPTION OF PROJECT

Type of Strategy: Green extension and Green extension + shortening of opposing green time. 11 intersections, 3.1 mile corridor.

Location: Tacoma WA,

Transit Agency: Pierce Transit

Issues Noted: Mostly technical. More analysis of control strategies.

Results Reported: Travel time savings, minimal impact on cross street traffic

OVERALL ASSESSMENT

Good project and paper. More detail would be helpful.

21. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Improved Traffic Signal Priority for Transit TCRP Project A-16

Author: University of Arizona (Systems and Industrial Engineering Dept) et. al.

Agency: Transit Cooperative Research Program, Transportation Research Board

Publisher: TRB

Date: October 1997

GENERAL REVIEW NOTES

This is an Interim Report on project to develop and test improved transit priority algorithms for traffic signal systems. Mentions priority project in Cermak Road (Chicago suburb). Uses networks on Speedway Blvd (Tucson) and Central Tucson as model scenarios (Does not mention actual implementation for these two cases). Describes 3 families of strategies as Local Signal Preempt., System Priority Coordination and Real-time Traffic Adaptive Signal Control. Discusses the use of CORSIM to evaluate transit priority strategies. Lengthy

appendices on literature review, Scenario Descriptions, Transit Priority Objectives, Signal Strategies and use of CORSIM.

DESCRIPTION OF PROJECT

Type of Strategy: several discussed.

Location: 3 noted – Cermak Rd (actual project), Speedway Blvd and Central Tucson model analysis.

Transit Agency: N.A.

Issues Noted: details of traffic control strategies and algorithms.

Results Reported: N.A.

OVERALL ASSESSMENT

Detailed discussion of traffic control strategies.

22. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Transit, traffic signals and capacity

Author: Stan Teply

Agency: ITE and CUTA meeting

Publisher: N.A.

Date: 1995 meeting?

GENERAL REVIEW NOTES

Presentation notes on the consideration of Transit in Canadian Capacity Guide. Overview of CCG methods.

23. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Bus Preemption under Adaptive Signal Control Environments

Author: Gang-Len Chang, Meenakshy Vasudevan & Chih-Chiang Su

Agency: University of Maryland

Publisher: Transportation Research Board

Date: December 1994

GENERAL REVIEW NOTES

Paper formulates a model for adaptive bus-preemption. Preemption is based on performance index that uses vehicle delay, bus schedule delay and passenger delay.

OVERALL ASSESSMENT

Essentially a research project with emphasis on mathematical model formulation.

24. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Model to Evaluate the Impacts of Bus Priority on Signalized Intersections

Author: S. Sunkari, P. Beasley, T. Urbanik, And D. Fambro

Agency: Texas Transportation Institute

Publisher: Transportation Research Board

Date: January 1995

GENERAL REVIEW NOTES

Research paper on development of a model to evaluate impacts of transit priority at signalized intersections. Model based on 1985 Hwy Capacity Manual. Data collected from a field test and simulation appears reasonable. Not much discussion of field tests in College Park, Texas

OVERALL ASSESSMENT

Some discussion of issues. Also discusses applicability of HCM analysis.

25. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Intersection Advanced Detection for Transit: Who Benefits, Who Pays?

Author: Gregg Snyder

Agency: Parsons Brinckerhoff Quade & Douglas (PBQD)

Publisher: Transportation Research Board

Date: January 1998

GENERAL REVIEW NOTES

Description of evaluation of transit priority scheme on Route 52 in Phoenix. Detailed analysis of before and after conditions related to bus delay, transit schedule reliability, auto traffic impacts. Cost benefit analysis provided for three intersections with positive results. Not too much information on control strategies and equipment.

DESCRIPTION OF PROJECT

Type of Strategy: Transit priority with signal preempt thru upstream bus detectors.

Location: Route 52 in Phoenix, Arizona. Collector St., 8 1/2 miles, intersects with a number of arterials.

Transit Agency: Phoenix Transit

Issues Noted: Mostly technical. Evaluates both cross-traffic and with-bus traffic impacts.

Results Reported: Positive improvements for transit and with-bus traffic. Minor negative impact for cross-street traffic.

OVERALL ASSESSMENT

Interesting project, good information on the evaluation but not too much on the traffic control strategies or the control hardware.

26. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: AVL Implementation Application and Benefits in the U.K.

Author: N. Hounsell & F. McLeod

Agency: Transportation Research Group, University of Southampton

Publisher: TRB

Date: 1998

GENERAL REVIEW NOTES

Describes the use of AVL for transit priority with reference to systems in Southampton and London. Description of AVL system components. Discusses AVL use to provide advance passenger information at bus stops in London and Southampton. Describes architecture scenarios for AVL and UTC communication (basically a local approach and a centralized approach). Southampton and Turin, Italy are centralized while London is local. Describes London example and benefit estimates.

DESCRIPTION OF PROJECT

Type of Strategy: AVL/UTC integration for transit priority

Location: London, U.K.

Transit Agency: N.A.

Issues Noted: System architecture and traffic priority strategy options

Results Reported: Benefits estimated for several cases using different control strategies.

OVERALL ASSESSMENT

Appears to reflect the state-of-the-art in AVL/UTC integration. Good discussion of system configuration and other considerations using AVL.

27. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Transit Priority Traffic Control Systems: European Experience

Author: Chris Bishop

Agency: MM Dillon Ltd

Publisher: Canadian Urban Transit Association

Date: October 1994

GENERAL REVIEW NOTES

This report provides a general overview of transit priority at signalized intersections in North America. Systems mentioned in North America are Toronto, Chicago, Edmonton, Charlotte (NC), Bremerton (WA). Outline literatures search on European systems and mail out questionnaire. Twenty responses to the questionnaire are summarized. Detailed descriptions, generally including descriptions of the system hardware, control strategies, results are provided in the report.

DESCRIPTION OF PROJECT

Type of Strategy: varies

Location: Five – London, Stuttgart, Zurich, Nancy, Angouleme

Transit Agency: five

Issues Noted: various

Results Reported: generally positive benefits for transit without significant problems for vehicular traffic.

OVERALL ASSESSMENT

An excellent background reference, particularly on European experience.

28. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Impact of Second Priority Signal Preemption on Kitsap Transit and Bremerton Travelers

Author: Thomas Williams, Mark Haselkorn, Kathy Alalusi

Agency: Dept of Civil Engineering, University of Washington

Publisher: Transportation Northwest, University of Washington

Date: October 1993

GENERAL REVIEW NOTES

Bremerton uses the Opticom Priority Control System, installed on 43 of 45 intersections in the City. Report evaluates results on 4 bus routes with one week with system in operation and one week with system not in operation. It is a second priority system, with first priority

given to emergency vehicles. The bus preemption is activated by the operator and can result in extended green or change side-street green to red. Signals may skip some phases to return to progression within 30 seconds. Evaluation indicated bus travel time reduced by about 10% overall. Vehicular delay increased at 4 intersections and was lower at 4 intersections. Overall vehicular delay reduced about 3.9%. Note that there were about 3 to 4 preempts per hour. Some excellent notes on implementation and operation, including bus operator comments.

DESCRIPTION OF PROJECT

Type of Strategy: Second level signal preempt using Opticom system. Actuated by bus operator.

Location: 43 of 45 signals in Bremerton.

Transit Agency: Kitsap Transit

Issues Noted: Required change in State legislation

Results Reported: Significant reduction in bus travel time. Vehicular results vary.

OVERALL ASSESSMENT

Very good report describing the system, the testing and the general experience.

29. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: The Cermak Road Bus Preemption Study Summary Report

Author: Civiltech Engineering Ltd & JRH Transportation Engineering Inc

Agency: Illinois Department of Transportation

Publisher: IDOT

Date: October 1993

GENERAL REVIEW NOTES

Report is a planning study for Cermak Rd Project. Includes information on current bus operations (about 49% of bus stopped time due to signals, 33% due to passenger boarding/disembarking). Cermak Rd has 15 signalized intersections with two separate control systems. Report discusses simulation of bus preemption. Results indicated significant improvement with updated signal timing and further improvements for transit with bus preemption. Analysis used Transyt 7F for signal timing and TRAF-NETSIM for corridor simulation. Good discussion of different bus priority technologies and also discusses technology requirements for this project. Corridor used by 2 Pace routes and 1 CTA route. Study recommended proceeding with implementation of a hybrid system. Est. cost \$774,000 for intersection and bus h/w.

DESCRIPTION OF PROJECT

Type of Strategy: Bus preemption thru detection and signal timing modification

Location: Cermak Rd, Cicero, IL (suburb of Chicago)

Transit Agency: Pace, Chicago Transit Authority

Issues Noted: Good discussion of technology selection considerations

Results Reported: Simulation indicated improvements for buses. Also traffic improvements thru updated signal timing.

OVERALL ASSESSMENT

Discussion of Cermak is based on simulation results only. Good discussion of available technology.

30. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Signal Priority Demonstration Final Report

Author: B. Funkhouser, W Nelson, K Semple

Agency: Pierce Transit

Publisher: Pierce Transit

Date: July 1996

GENERAL REVIEW NOTES

Report provides a detailed description of the Pierce Transit project. Project installed on a 3.1 mile long corridor (S. 19th St) with 11 intersections. Fifteen buses were equipped for the project. Four technologies evaluated.

Used two different technologies (Opticom and Loopcomm). Report provides assessment of each. Both worked but Opticom data logging capability was used. Different control strategies were tested. Results indicated reductions in bus travel time of about 5% to 7%. Some side-street traffic delay, in the order of 1 to 4 seconds that was not felt to be significant. Also noted several bus stops moved from near-side to far-side to make better utilization of bus priority.

DESCRIPTION OF PROJECT

Type of Strategy: Bus preemption thru detection and signal timing modification

Location: S 19th St in Tacoma, Wash

Transit Agency: Pierce Transit

Issues Noted: No major issues noted

Results Reported: Evaluation indicated improved travel times of about 5% to 7% for buses and very minor increase in side street delay.

OVERALL ASSESSMENT

Excellent report on evaluation, traffic strategies, and the technology.

31. LITERATURE REVIEW NOTES:

PUBLICATION DATA

Title: Development and Evaluation of Transit Signal Priority Strategies

Author: M. Garrow & R. Machemehl

Agency: University of Texas at Austin

Publisher: Texas Transportation Institute/ U.S. DOT

Date: August 1997

GENERAL REVIEW NOTES

Research report on Transit Priority at signalized intersections. Contains an extensive literature review and an overview of transit priority experience. Discusses passive and active control strategies. Corridor in Austin, Texas was used for TRAF-NETSIM model analysis of a wide range of transit priority strategies, including passive and active. Considers off-peak and peak strategies. Conclusions tend to indicate that passive strategies may have some limitations. Also some comments on different active strategies and bus stop placement.

DESCRIPTION OF PROJECT

Type of Strategy: Simulation modeling of corridor

Location: N.A.

Transit Agency: N.A.

Issues Noted: Discussion of applicability of different strategies based on simulation results.

Results Reported: varies with strategies.

OVERALL ASSESSMENT

Excellent research report.

32. LITERATURE REVIEW NOTES

Other Documents for General Reference (from Paradigm Library):

- Highway Capacity Manual Third Edition (general traffic reference), updated 1997.
- Notes from Joint Seminar on Traffic Engineering and Transit Planning, W. O'Brien & W. Sproule, Joint Meeting of CITE & CUTA, Regina, 1995.
- The Canadian Transit Handbook Third Edition (General section on Transit Priority in Chap. 14), 1993.
- Traffic and Transportation Engineering Handbook Second Edition (Chapter 24 provides overview of Traffic Signals), 1982.
- Traffic and Highway Engineering, N. Garber & L. Hoel, West Publishing Co., 1988.
- Manual of Uniform Traffic Control Devices, Ontario Ministry of Transportation. Ronen House Publishing.
- Geometric Design Standards for Ontario Highways, Ontario Ministry of Transportation, Ronen House Publishing.

Appendix B

SURVEY ON TRANSIT PRIORITY SYSTEMS

April 2000

**SURVEY ON TRANSIT SIGNAL PRIORITY SYSTEMS:
SUMMARY OF RESULTS**

In December 1999, the Canadian Urban Transit Association (CUTA) undertook a survey of the 115 largest North American transit systems, each with more than 100 buses, to determine how widespread is the use of transit signal priority. Surveys were faxed to 21 transit systems in Canada, 93 in the United States of America, and one in Puerto Rico. 86 systems (or 74.8%) responded. Among the patterns that have emerged from the data:

1. A handful of transit systems have already implemented transit priority measures at a large number of intersections. While 31 transit systems reported that they are using transit signal priority, the majority of intersections currently equipped for this purpose can be found in just 3 service districts.
2. The number of intersections to be equipped with transit signal priority will more than double by the year 2003.

More than one-third of survey respondents reported using transit priority at signalized intersections of one kind or another. (See Table 1) And, of the types of signal priority employed, transit-only signals or phases¹ were reported by fully a quarter of the respondents. Approximately 50% of survey respondents reported transit signal priority projects underway, or plans to implement them, in the next five years. Altogether, 70% of the transit systems responding to the CUTA survey, (and 52% of all transit systems in North America with over 100 buses) are either already using priority measures or have plans to do so in the near future.

Table 1
Survey on Transit Signal Priority Results

	Number of Respondents	Percent of Respondents
Transit signal priority <i>in use</i>	31	36.0 %
Transit-only signals or phases <i>in use</i>	23	26.7 %
Transit signal priority projects <i>Underway</i>	38	44.2 %
Transit signal priority projects <i>planned</i>	47	54.7 %
At least one of the above	60	69.8 %

¹ Often white vertical, horizontal or diagonal bars on a black background. These are referred to as "cigar signals" in some jurisdictions.

Survey respondents reported a total of 684 intersections currently providing transit priority. Among transit systems reporting a *specific number* of intersections with transit priority, the Toronto Transit Commission reported 172 intersections equipped, Kitsap Transit (Bremerton, WA) 100, and the Santa Clara Valley Transit Authority (San Jose, CA) 84. On average, respondents with priority measures have implemented them at 24 intersections. Yet, in the overwhelming majority (75%) of cases, respondents using transit signal priority reported fewer than 20 intersections equipped to date. This imbalance between the average number of intersections with transit priority per service district and the median number per district (detailed in Table 2) underlines the leadership role being played by a relatively small number of transit systems at this point in time.

Table 2
Number of Intersections Involved on Average

	Mean	Median
Transit signal priority <i>in use</i>	24	9
Transit-only signals or phases <i>in use</i>	11	6
Transit signal priority projects <i>underway</i>	28	11

Survey respondents reported 248 intersections providing transit-only signals or phases. Among transit systems reporting a *specific number* of intersections with transit-only signals or phases, the Sacramento Regional Transit District reported 56, Tri-Met (Portland, OR) 40, and the Port Authority of Allegheny County (Pittsburgh, PA), 30 intersections. More than two-thirds (69.6%) of those respondents who reported intersections with transit-only signals or phases had fewer than 10 intersections equipped for the purpose. The imbalance between the average number of intersections with transit-only signals or phases per service district and the median number per district is less pronounced than for transit signal priority in general.

Thirty-eight respondents reported that projects to implement transit priority are currently underway, involving more than 862 intersections. No distinction was made regarding the type(s) of priority measures being pursued. Among the more ambitious programs, Tri-Met will equip 150 more intersections by 2001, and Pierce Transit (Tacoma, WA) 123 more intersections by April 2002. When completed, the various projects underway will bring the total number of intersections providing transit priority to more than 1,500, an increase of more than 120% in approximately three years.

Implementing transit signal priority is clearly an area of growing interest to the transit industry in North America, with 70% of responding transit systems pursuing the implementation of this technology. As a result, CUTA has conducted a study on this topic under its Strategic Transit Research Program (STRP), entitled **Design and Implementation of Transit Priority at Signalized Intersections: A Primer for Transit Managers and a Review of North American Experience (STRP Report 15)**. [Please consult CUTA's web site <www.cutaactu.on.ca> for more information about this and other STRP reports.